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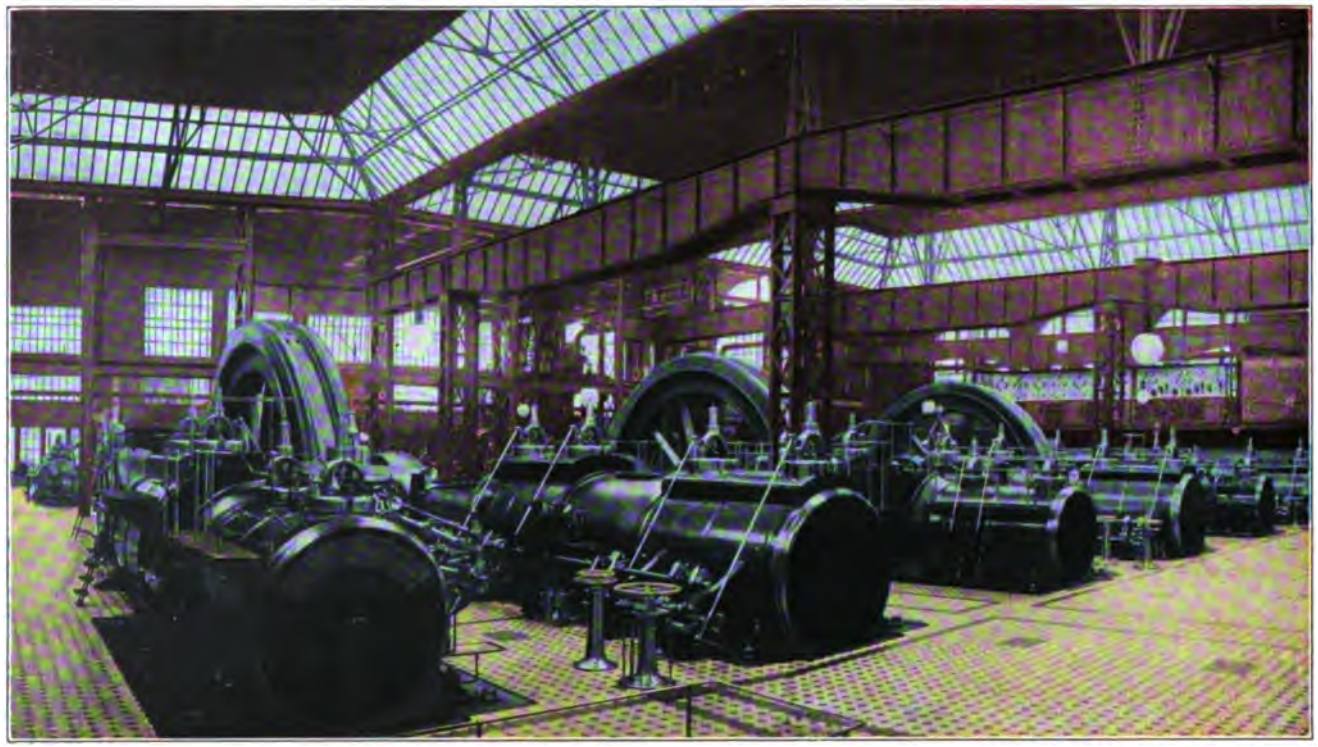

LARGE ELECTRIC RAILWAY STATION WITH HORIZONTAL ENGINES

# MODERN ENGINEERING PRACTICE

## STEAM·ELECTRICITY·MECHANICS

TEN VOLUMES

EDITOR IN CHIEF

**FRANK W. GUNSAULUS**

PRESIDENT ARMOUR INSTITUTE OF TECHNOLOGY

Assisted by a large corps of Distinguished Specialists and Technical Experts

VOLUME VIII.

ELECTRICITY-LIGHT-POWER

AMERICAN SCHOOL of CORRESPONDENCE
at ARMOUR INSTITUTE of TECHNOLOGY
CHICAGO ILLINOIS

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# MODERN ENGINEERING PRACTICE

## STEAM • ELECTRICITY • MECHANICS

TEN VOLUMES

A Reliable Guide for Engineers, Mechanics, Machinists and Students. Illustrating and Explaining the Theory, Design, Construction and Operation of all kinds of Machinery. Containing nearly Four Thousand Pages, illustrated with more than Two Thousand Valuable Diagrams, Working Drawings, full-page Plates and Engravings of Machines and Tools

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ELECTRICITY-LIGHT-POWER


AMERICAN SCHOOL of CORRESPONDENCE at ARMOUR INSTITUTE of TECHNOLOGY

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# Volume VIII.

ELECTRICITY: LIGHT POWER

## SECTION I.

# TYPES OF DYNAMO-ELECTRIC MACHINERY: (Direct Current.)

We will now consider the general characteristics of the various types and the methods and materials of construction of dynamo-electric machinery.

Within the last ten years dynamo-electric machines have been very extensively introduced, and great improvements have been made in their construction. In former years the generator was often poorly built; its mechanical faults considerably decreased its usefulness, and led to frequent repairs. High grade generators such as are now manufactured are much stronger mechanically, simpler in construction, more reliable in operation and more durable. An important advance is the considerable reduction in electrical and frictional losses. This reduction gives both increased efficiency, and less danger of overheating.

In recent years the special design of electric machinery for particular classes of work has become a highly important feature of electrical engineering, owing to the many novel applications for which this class of machinery is now used.

The following pages contain numerous modern types of electric machinery, examples being chosen from actual practice to illustrate the most modern usage.

### CONSTANT CURRENT AND CONSTANT POTENTIAL GENERATORS.

Direct current generators may be divided into two types: those furnishing a variable current at a fixed voltage or potential; and those giving a constant current, the potential in this case being made to vary with the requirements of the load.

By far the greater number of the modern generators are of the constant potential type. These are used in practically all

power and incandescent lighting circuits. The constant current type is devoted mostly to arc lighting. It should be noted however that in many instances arc lights are now run from the constant potential system.

## METHODS OF DRIVING GENERATORS.

We may distinguish the following principal methods of driving generators. These methods are used according to local requirements.

**Direct Steam or Gas Engine Driven** — (Including the "Engine Type");

**Indirect Steam or Gas Engine Driven** — (Belt, Wire and Rope Driving);

**Water-Turbine Driven;**

**Steam-Turbine Driven.**

**Direct Steam or Gas Engine Driven Generators,** Generators of large size used in connection with steam or gas engines are now commonly driven directly from the engine shaft. That is to say, the engine shaft is extended out to one side of the engine, and is provided with an extra bearing. Onto the extended shaft the revolving part (usually the armature) of the generator is keyed.* Often the shaft is slightly tapered, and the armature is driven onto it by screw jacks, under great pressure. Some manufacturers bolt the revolving part of the generator directly to the fly-wheel.

A generator having its revolving part carried by the engine shaft is usually spoken of as an "**engine type**" generator. Such a generator has no shaft of its own and no bearings, both shaft and bearings being provided by the engine maker. Other direct-driven generators have both shaft and bearings, the shaft carrying a coupling flange which is bolted directly to a similar flange on the engine shaft. A fly-wheel is usually provided, since

*Note.—In direct current generators it is in nearly all cases the armature that revolves. In some alternating current generators the armature revolves (inside of a stationary field), while in other types of this class the armature is stationary, and the field magnets are made to revolve Whichever it is that revolves, armature or field, it is evident that the essential process, the "cutting of lines of force," is the same.

the rotating part of the generator is not sufficiently massive to give steadiness of running.

An important advantage possessed by the direct connected generator is the small floor space required. In belt driving it is customary to place the generator at a considerable distance from the engine, and the intermediate floor space is usually not available for other purposes.

**Indirect Steam or Gas Engine Driven Generators.** In the indirect methods of driving, (including the belt, wire and rope systems), generators are run at a great variety of speeds by various kinds of belt, rope and wire driving gear. Small generators are ordinarily driven by one or the other of these indirect methods, several generators being commonly connected to one engine. Generators of from 10 to 50 K. W. capacity usually carry a small metal, wooden or composition pulley which overhangs the main bearings. If the generator is of larger size a third or "outboard" bearing is provided to relieve the bending strain caused by the belt pull.

**Water-Turbine Driven Generators.** The recent development of water-power in different parts of the country has given rise to the third type or water-turbine driven generators. These machines are of a very different design from those driven by steam engines. Engine driven generators ordinarily have a horizontal shaft, whereas the turbine, being usually at the bottom of a vertical tunnel, requires a vertical shaft, onto which the revolving part of the generator is directly bolted or keyed. The generator is thus, as it were, turned on its side, and an entirely different system of stresses has to be provided for. Such generators are usually of large size, ranging from 100 to 3000 K. W. Even larger sizes are occasionally constructed. This fact is due to the use of water wheels or turbines of great size, the division of the water-power among a number of small turbines being unsatisfactory. Such generators are almost invariably direct driven from the turbine shaft.

**Steam-Turbine Driven Generators.** The next main division of generator-driving systems comprises the steam-turbine driven generator. This system is comparatively new, having been developed within the last few years in England and America,

mainly since the invention of the Parsons Steam Turbine. Generators so driven, show still further variation from the usual types The steam-turbine rotates at very high speeds and it is not practicable to use belting with it. The system of direct driving is therefore employed, the revolving part of the generator being bolted or keyed to the shaft of the turbine. Owing to the enormous speed at which the turbine revolves (sometimes several thousand revolutions per minute) the design of the generator is greatly modified. The voltage of a generator depends upon three factors: the speed of revolution, the magnetic flux, and the number of turns in series on the armature. The speed in this particular case being so excessive, the armature is made relatively small and the field is of the simple bipolar type.

## STEAM AND GAS ENGINE DRIVEN GENERATORS.

**Direct- and Belt-Driven Generators.** It is impossible to fix any limit between the sizes of generators which are belt-driven and those which are direct driven. As a general thing, generators of less than 200 K. W. capacity are driven by belting, while nearly all of 500 K. W. and over are driven direct from the engine shaft. Between these limits of 200 and 500 K. W., both belt and direct-driven types are extensively in use. As a general rule however designers now prefer the direct-driven types for all except the very smallest sizes.

It is also impossible to fix any general limits of generator speed. The standard types of stationary engines of large sizes are, generally speaking, slow-speed. From 275 revolutions per minute, in the moderate size engines, the speed decreases as the size of the engine increases. Seventy-five or 80 R. P. M. is the usual speed of the large central station engines.

Since the speed is fixed by the requirements of steam engine design, the direct-driven generator is designed to meet these conditions. Such machines have from 6 to 28 poles, the number of poles increasing with the size of the generator. The revolving armature is made quite narrow, but of great radial depth, the diameter in the large sizes being sometimes 30 feet. Such an armature differs very strikingly from the compact armatures of

small diameter used in the older belt-driven, high-speed generators.

The change from belt-driven to direct-driven generators has been very gradual. In 1893 several of the larger companies had constructed direct-driven generators of large size, and this date may be fixed as about the beginning of the present era of direct-driven generators.

**Advantages of Direct-Driven Generator.** In all applications of very large generators, where it is possible to do so, it is better to install one of the direct-driven types, as even the best system of belting is unsatisfactory for transmitting great power. Moreover, the introduction of shafting, counter shafting and belt, rope or wire driving, causes losses by friction, which are sometimes excessive when large generators have to be driven. These losses are avoided by the use of direct-driven generators. Also high-speed belt-driven generators necessarily have armatures of small diameter, since larger diameters would not be suitable for driving at very high rates of revolution. Armatures of small diameter, however, in which the windings are compactly placed, are very imperfectly ventilated, and often give a great deal of trouble by overheating. Faulty insulation and poor efficiency are the result.

The direct-driven generator, on the other hand, operating at slow speed, has an armature of much larger diameter, so that the windings are spread out over a much greater surface. This gives facilities for practically perfect ventilation. As a rule the direct-driven generators keep cool much better than the belt-driven type, and will stand far greater overloads.

Another point of great importance in determining the type of generator to be installed is the ease with which repairs can be made.

In the older belt-driven armatures the coils are compactly wound and bound about by insulation; the burning out of a coil usually makes it necessary to take the armature to pieces for repairs. In the modern direct-driven armature the coils are spread out over a large surface, and are well separated from each other. Repairs are, therefore, made with the utmost facility. Any individual coil may be separately removed. Such repairs,

owing to the perfect ventilation of the armature, are rarely needed. An armature of this type will take severe overloads without permanent injury. Ordinarily however such machines are more expensive to install than the belt-driven types. There are indeed some cases in which the belt-driven generator is to be preferred — particularly in the smaller sizes, on account of the smaller first cost, and the ease with which it may be adapted to engines already in use.

The leading manufacturers are now making belt-driven moderate-speed generators (500 R. P. M. for example), in which some of the important features of the direct-driven type are preserved. These machines have fairly large, well ventilated armatures, and will take quite heavy overloads. They are rapidly supplanting the old generators with small, close-wound and unventilated armatures. In general, therefore, it may be said that present practice (1902) is, in large power plants, to use direct-driven slow-speed generators, and in smaller installations to use belt-driven generators. These belt-driven generators, as far as possible, embody the best features of the direct-driven type.

It should however be noted that the steam-turbine driven generator, now slowly coming into use, completely reverses the usual tendency toward slow-speed armatures of large diameters. The steam-turbine speeds range from 1200 to 3500 R. P. M., and the use of direct current generators, rotating at such speeds, is open to question. Commutation would be very difficult, and ventilation of complicated armature windings would be almost impossible. Generators driven by the steam-turbine are, as a rule, of the alternating current type and do not therefore come under this part of the subject. Alternating current machines are considered separately.

## WATER-DRIVEN GENERATORS.

Reference has already been made to the general considerations governing water-driven generators. Such generators usually belong to the alternating current class, although the direct current system is entirely practicable. The reason for generally using the alternating current system in this connection is as follows. As a rule, the water-power is not located near manufactur

ing centers, and so the electric supply has to be sent out over considerable distances. Moreover, the alternating current has important advantages whenever electric power has to be conveyed over a long distance. For these reasons the use of the direct current system is limited

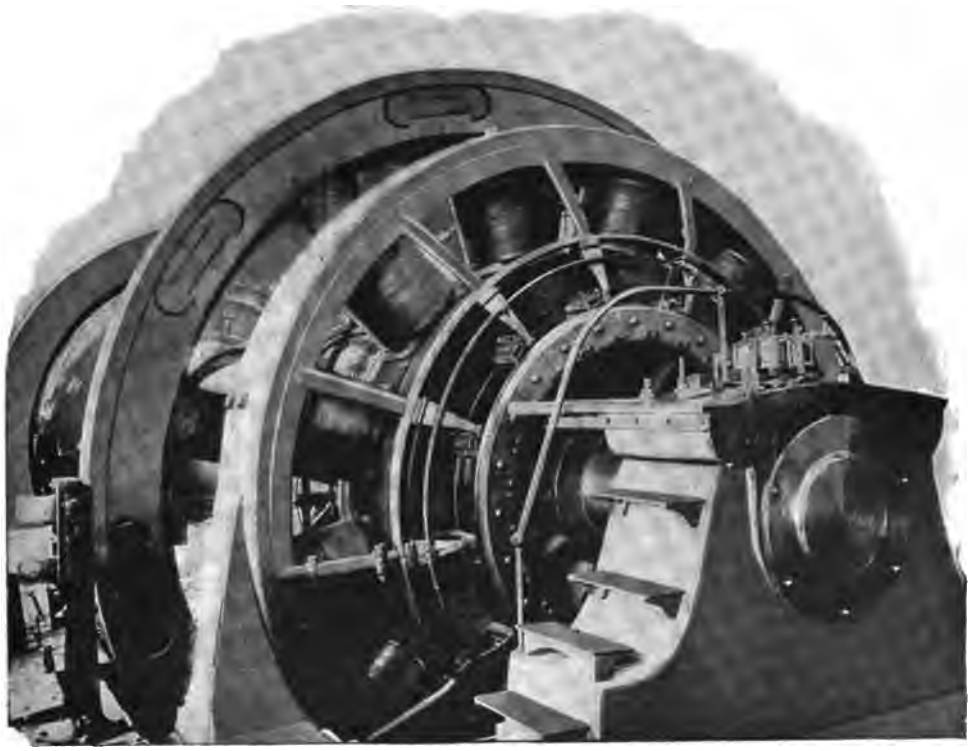


Fig. 1. General Electric Company's Direct-Connected Railway Generator, 550 K. W.

mostly to cases where the current is transmitted over comparatively short distances.

## REPRESENTATIVE DIRECT-DRIVEN GENERATORS.

**General Electric Co.'s Railway Generator.** Figure 1 shows the General Electric Company's direct connected "railway" generator. Such machines represent a high type of electrical

efficiency and mechanical soundness. They range in size from 2400 K. W. (3200 H. P.), having 28 poles and running at 75 R. P. M, down to 100 K. W., running at 275 R. P. M., and having 6 poles. The yoke of the field magnets, (seen in the illustration as the outside circular frame surrounding the coils), is of cast iron, of very massive design. The upper and lower halves of this cast-iron ring or yoke are cast separately, and are fastened together by bolts. This yoke carries the poles of the field, which are solid steel castings, accurately fitted and bolted to the inner face of the yoke. The bolt-heads are seen in the illustration. These poles are keyed in in such a way that they may be slipped out sideways, one at a time, in case of accident. These steel poles are, in the larger machines, made with laminated polar faces.* Each field-coil is separately wound and slipped into position upon the pole.

The armature windings and core are built up upon the rim of a strong central spider, shown in Figs. 3 and 4. This spider is so designed that it serves furthermore as a powerful fan, keeping a constant air blast passing through the armature windings. This is a feature of great importance in securing cool running. The armature core itself is laminated, the stampings of iron being put into position in such a way as to leave numerous radial air passages through the whole mass of the core. By means of these the blasts of air, coming from the arms or blades in the spider, pass

* All high-grade generators and motors now have laminated armature cores, and many of them have laminated field poles, though the field magnets themselves are usually made with solid cast-iron or cast-steel cores. A "laminated" core is made up of a great number of thin sheets of soft iron or steel pressed solidly together, making what is practically a solid mass of metal. It was found in the use of solid iron cores that eddy currents (see following Paper on Direct Current Dynamos, were formed which reduced the efficiency of the machine. The soft-iron sheets, however, being magnetically insulated from each other, (sometimes by a thin coating of shellac, or by a thin film of rust), effectually prevent eddy currents.

Pole pieces in some machines are laminated for the same reason. By cutting away every alternate sheet of metal at the horns of the pole pieces it is possible to give the magnetic field just the degree of density that is best for the smooth running of the machine. This is done in the Westinghouse machines, and other makers produce somewhat similar effects by cast-steel pole pieces of special design.

through the armature windings. Slots are also provided upon the face of the core to receive the conductors.

The armature coils are bent into shape upon forms or patterns made of the exact shape that the coil will have upon the armature. After being bent into shape the coils are wrapped with insulation and fastened into the slots upon the armature by means of little insulating wedges or keys. A single coil is shown in Figure 2.

These wedges generally do away with binding wires, which were often found to interfere with the armature insulation and ventilation. A great advantage of this method is that a single

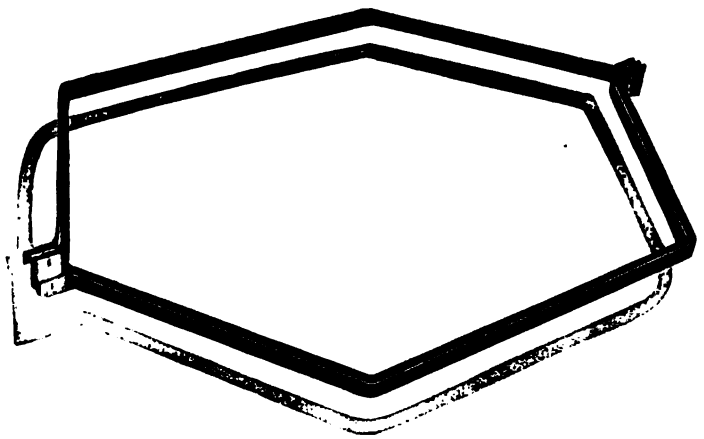


Fig. 2. Armature Coil for General Electric Generator.

coil or part of a coil may be removed from the armature separately.

It will be remembered that in multipolar machines the same potential exists or should exist at several points around the circumference of the armature, owing to the simultaneous action of the different poles. In the railway generator, as in other advanced types, such points of nearly equal potential are connected together by massive conductors arranged along one of the end faces of the armature. By this method any slight irregularities of adjustment (which would otherwise cause an unequal distribution of current around the armature) are compensated. These conductors are known as equalizer rings and are an important feature of modern machines of this class.

Commutators and brush holders are of massive design, allowing large surfaces of contact and ample chance for ventilation.

The commutator brushes are carried on a ring as seen in Figure 5. This ring is moved by means of the rod and hand-wheel seen at the left of the figure. The complete machine, together with the engine shaft, bearings and fly-wheel, is seen in Figure 1.

These machines are compound-wound and the voltage varies from 525 at no load to 575 at full load. By shunting the series

Fig. 8. Rear View of General Electric Armature Showing Equalizer Rings.

field, this over-compounding may be reduced as desired. Two or more of these generators will work perfectly in parallel.

The General Electric Company makes very similar machines for lighting and general power service. The essential difference between these and the railway generator is the voltage. The lighting and power generators are usually wound for from 125 to 300 volts, while railway generators usually give from 500 to 550 volts. The danger of injury to the armature through short cir-

cuits is practically removed by the use of massive armature conductors made of bar copper.

All these armatures are constructed on what is known as the "iron-clad" principle; that is to say, the conductors, as we have seen, are not wound upon the surface of the armature core, but are imbedded quite deeply in slots which are cut through the sheet metal core. In this way the soft copper conductors with their

Fig. 4. Front View of Armature and Commutator.

insulating material are protected from all injury by the projecting portions of the iron core.

Similar machines are made by the **Crocker-Wheeler Company.** Fig 6 is an excellent representation of this company's engine-type generator.

In the Crocker-Wheeler machines the magnet frame is a cast-iron ring, stiffened by flanges like a girder; the upper and lower

halves are cast separately and are accurately fitted together and held by bolts. The upper half may be lifted off from the machine if repairs are necessary.

In all these direct-driven generators the lower part of the

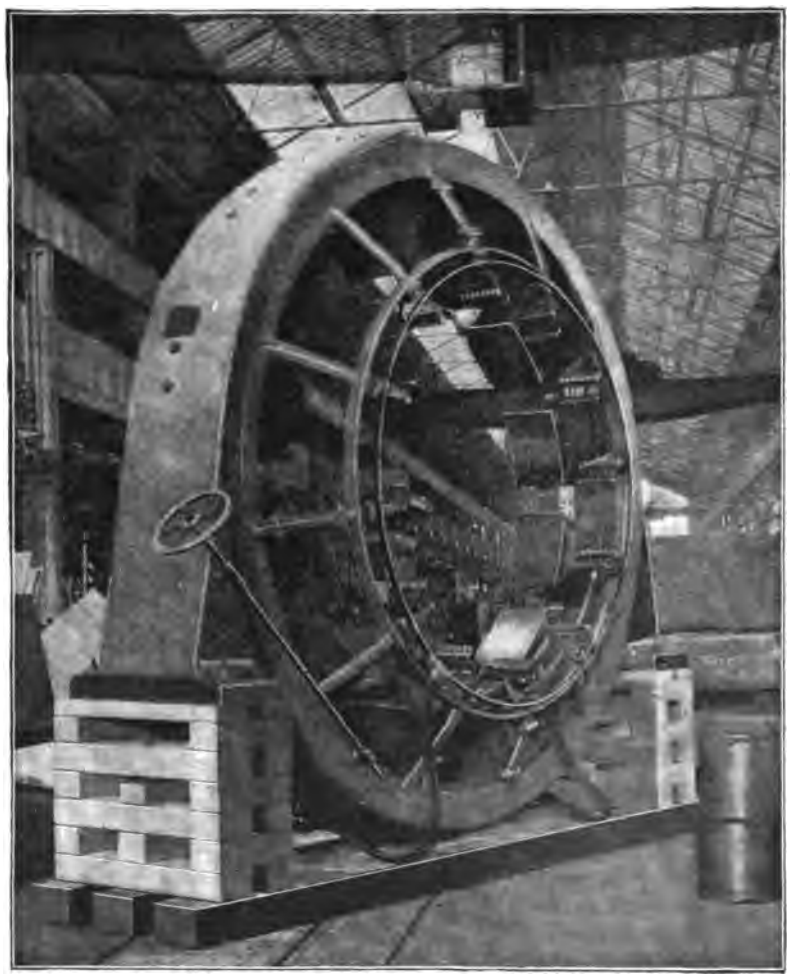


Fig. 5. Field and Brush Holders of a General Electric Generator.

magnet frame carries iron feet which are bolted down to a supporting base.

**Westinghouse** Engine-Type Generator. Fig. 7 shows a Westinghouse direct current engine-type generator. It has ne-

ther shaft nor bearings, both of these being supplied with the engine. This particular machine is wound for 125 volts. The field frame is of soft steel and is cast in two parts. These two parts are divided from each other in a vertical plane; that is, the right and left hand sides of the field may be unbolted and drawn apart on slide rails provided for this purpose. The poles are cast welded* into the yoke or frame of the magnets; and the field-coils, separately wound, are slipped onto these poles,

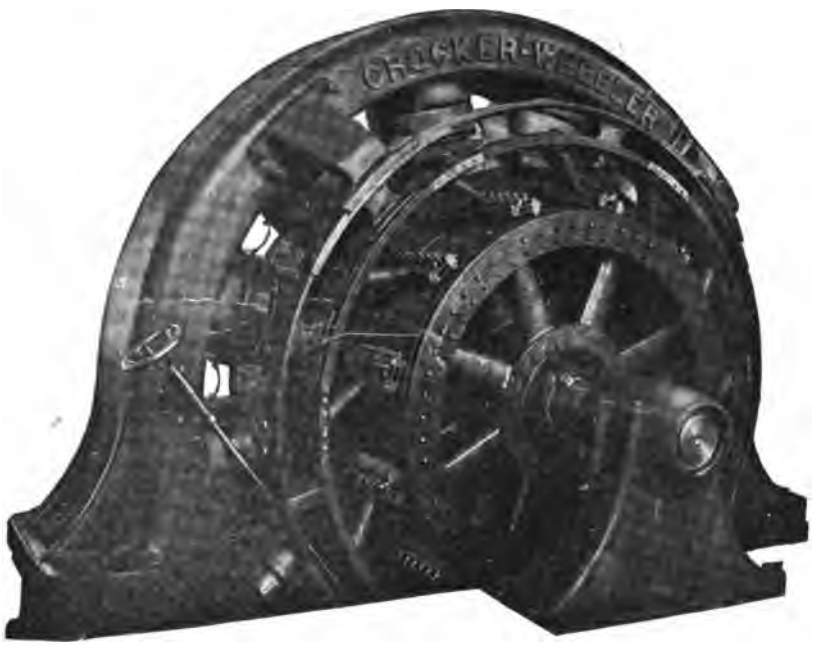


Fig. 6. Crocker-Wheeler Engine-Type Generator.

where they are bolted into position. The armature core, carried by a cast-iron spider, is built up of thin discs of carefully annealed steel. Air ducts are left through the core as in the types already discussed, and ventilation is practically perfect. Fig. 8 shows a 200 K. W. Westinghouse generator connected to a Westinghouse steam engine.

The armature windings are usually of heavy bar copper set

*See Page 35.

into grooves in the surface of the armature core. Fig. 9 shows this construction very clearly. The commutator, built up of hard rolled copper, insulated with specially prepared mica of great hardness, has excellent ventilation, and provides a surface that wears evenly.

Fig. 7. Westinghouse Engine-Type Generator.

Years ago many inferior makes of machines carried commutators of soft copper insulated with soft material. Such commutators wore rapidly into irregular grooves, which made good commutation impossible. High-class machines are now built with practically indestructible commutators. This is one of the most vital features of direct current work, and careful examination of the commutator is necessary in making a choice of machines. Fig. 10 shows the complete armature of a Westinghouse 800 K. W.

engine-type generator, and Fig. 11 shows such a machine assembled upon the engine shaft, together with the enormous fly-wheel. This fly-wheel is necessary for smooth running at slow speeds, such as are common in direct-driven machines.

The Westinghouse direct-connected railway generator is shown in Fig. 12. Bearings are provided by the engine builder, the armature of the generator being mounted upon the shaft of the engine. The field castings are divided vertically, and the two halves are bolted together so firmly as to constitute a good magnetic circuit. By this construction it is rendered easy to inspect the armature at any time by unbolting the field and moving it sideways. This arrangement is particularly valuable in engine rooms where there is but little head room, or where overhead cranes for handling heavy castings are not available. Machines of similar design are however constructed by the Westinghouse E. & M. Co., having a field divided horizontally, the top half being removable by means of a suitable crane. The bolts for securing together the two halves of the field are in this case at the sides of the field.

Railway generators are usually overcompounded, a rise of 10% in the voltage being allowed for from no load to full load. The compound windings for one of the pole pieces are shown in Fig. 13. Shunt and series coils are mounted upon a light metallic skeleton frame, which is slipped on over the pole piece. The coils are well ventilated and easily removable.

Fig. 14 shows the core for the armature of a railway generator. This core, mounted upon a cast-iron spider, as shown, is slotted to receive the windings, rows of ventilating ducts being left around the circumference. Fig. 15 shows the complete armature and commutator, the temporary shaft seen in Fig. 14 being omitted in Fig. 15. In the latter figure the armature is seen resting on the floor, the delicate insulated windings being protected from injury by their position, since they are sunk beneath the surface of the core.

Fig. 16 shows a group of these machines as installed at the United Traction Company's plant at Allegheny, Pa. These machines are each of 500 K. W. capacity, and uniform speed is secured by means of the enormously heavy fly-wheels shown.

They are driven by horizontal engines, which are not clearly shown in the illustration.

The **Lundell** Split-Pole Generator, manufactured by the Sprague Electric Co., is shown in Fig. 17. In this generator

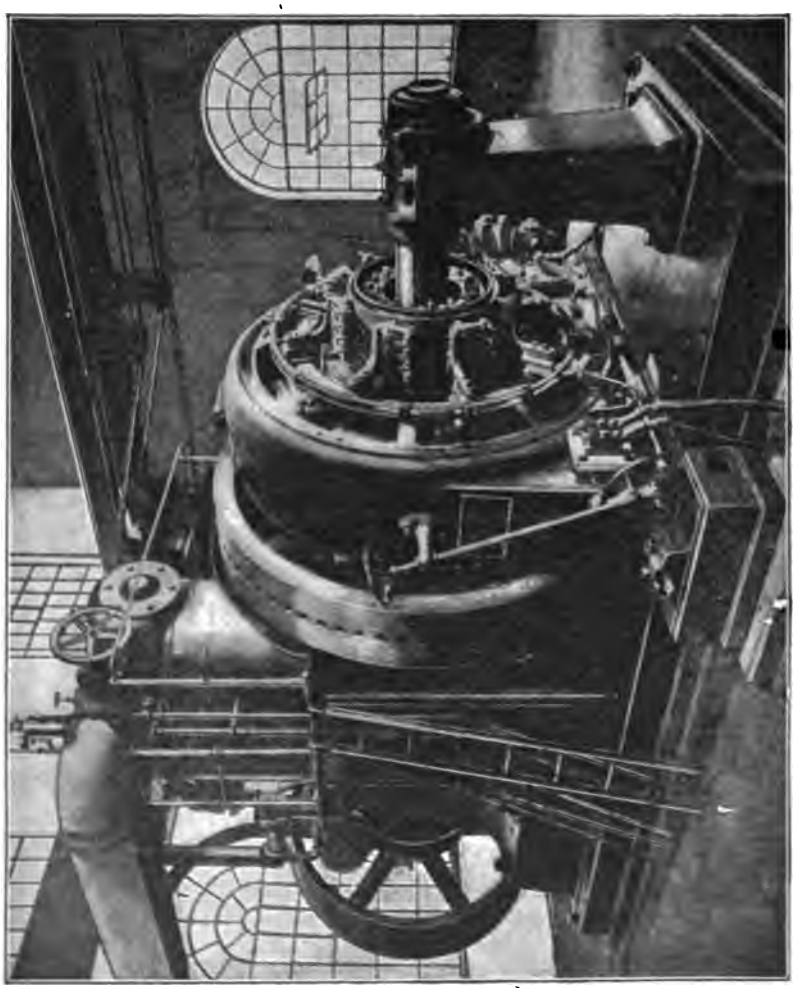


Fig. 8. Westinghouse Engine and Generator.

the pole pieces are divided into two approximately equal parts; one of these parts has a large extension along the face of the pole, and the other part has a much smaller extension. The result is that a small exciting current will fully magnetize one

part, but will not fully magnetize the other. When this current is increased the magnetism of the part having a large polar extension is slightly increased, while the part with the small extension has its magnetism more rapidly increased. This results in diminishing the distortion of the field, and consequently the point of commutation remains practically fixed. It is claimed by the manufacturers that this device does away with the necessity of shifting the brushes, the brushes being once set properly.

The yoke is circular, and consists of two steel castings. The pole pieces are bolted to the yoke. The armature is of large diameter, and is of the iron-clad type. The core is laminated and

Fig. 9. Armature of Westinghouse Generator.

built up of soft annealed sheet-steel punchings, thoroughly japanned, and secured to a spider, which is keyed to the shaft. The commutator is unusually massive, giving abundant capacity, without excessive heating. The commutator bars are of hard drawn copper, carefully insulated from each other with the best grade of mica. The completed commutator is solid, accurately turned and smooth running. The split-pole type of generator is made in sizes ranging from 25 K. W. to 1000 K. W.

**The Triumph Electric Company** manufactures multipolar generators of both slow and moderate speed types, as shown by the accompanying illustrations. Fig. 18 shows the Triumph

multipolar direct current generator mounted upon the bedplate of a horizontal gas engine. Fig. 19 shows the Triumph generator as adapted to use on shipboard, mounted upon the bedplate of a vertical engine. Fig. 20 shows a larger machine also mounted upon the shaft of a vertical engine.

Fig. 21 shows the completed field frame and pole pieces of a Triumph generator, with shunt and series windings in posi-

Fig. 10. Complete Armature of 800 K. W. Westinghouse Generator.

tion. Fig. 22 shows a complete Triumph armature. No shaft is provided, the armature being designed for direct mounting upon the shaft of an engine.

Fig. 23 shows the **Fort Wayne Electric Works'** 50 K. W. direct-driven multipolar generator connected to a horizontal

engine. This machine, together with others manufactured by the Fort Wayne Works, comprises what is known as the "Wood" System.

The direct-driven generators range from 15 K. W. upwards; the smaller sizes have 6 poles and the largest size 8. These machines are designed with special reference to quiet, steady running, a feature which makes them available for use in hotels and office buildings.

The cores of the field magnet poles are of fine laminated iron cast into the body of the frame by a special construction. The magnetic circuit is undoubtedly good.

The armature is of the "iron-clad" type, and is wound with coils formed separately on patterns. The core is of laminated sheet iron. Light binding wires are applied to the armature coils, but the core is made with ventilating ducts, and a constant circulation of air is maintained through the armature windings.

The illustration shows large commutator surface and good brush area. The brushes are shifted by turning a small hand-wheel seen at the left of the illustration, directly below the main bearings. These machines run at the comparatively low speeds of 375 to 250 R. P. M.

A representative type of direct-driven generators, manufactured by the **Bullock Electric Mfg. Co.**, is illustrated by Fig. 24. This shows the 800 K. W. type "I" direct current Bullock generator, direct connected to a cross-compound Corliss engine. Like other direct-driven generators, this machine operates at the very low speed of from 85 to 90 R. P. M. These machines are designed to meet the requirements of different engines. It will be seen that the field yoke is divided horizontally, being cast in two semicircular sections, which are bolted together midway of the height of the generator. The pole pieces, of laminated soft steel, are so formed as to produce a uniform magnetic flux across the air-gap. In the Bullock machines the poles are bolted to the yoke, the nuts being concealed in the interior of the pole pieces.

These generators are usually overcompounded for a rise in potential of 3% from no load to full load, but this compounding may be varied as required.

The armature core is carried upon a massive spider, shown in Fig. 25. The core itself is built up of thin sheet steel of high magnetic permeability. Ample ventilating ducts are provided as usual. Interchangeable armature windings of copper-bar or wire

Fig. 11. Complete Westinghouse Generators. Mounted.

are used. Each conductor is wound with tape, then the conductors for a coil are grouped together and taped as a whole. After this the coil is dipped into an insulating compound. It is then still further insulated with rope paper, mica, and bond

paper, and is then armored with red fibre (or at least so much of the coil as is to be in contact with the armature slot). These coils are then baked at about 350° F. under pressure, this process removing all moisture. Insulation thus built up is of a very high grade, and the coils when placed upon the armature require no further insulation. Coils are held in position by wedges of hard wood, which are driven into notches in the armature slots. No band or binding wires are used. Fig. 26 shows the completed armature for a 76 K. W. Bullock generator. Fig. 27 shows the 800 K. W. Bullock generator disconnected from the engine.

At the top of Fig. 27 is shown a small wheel carried by the yoke of the machine. Two similar wheels are also carried by the frame of the machine, but are hidden by the base plate. These wheels support the large ring which carries the brush-holder mechanism. By means of this device the position of the brushes is adjusted through a handwheel, seen at the right of the figure.

Fig. 28 shows a 15 K. W. Bullock generator direct connected to a gas engine. Between the gas engine and the generator is seen a flexible coupling, carried within the body of the fly-wheel. Steadiness of running, ordinarily so difficult to obtain with gas engines, is insured by the use of a compound gas engine, by fly-wheels of massive construction, and by the mass of the armature.

Fig. 29 shows the efficiency curve for the 200 K. W. Bullock generator. The figures given at the base of the diagram show quarter, half, three-quarter and full loads and overloads. Efficiency is indicated in percentage, at the left of the diagram. The machine possesses high efficiency at full load, and the efficiency does not appreciably decrease until the load has fallen to one-half of the full load of the machine. It will, furthermore, be noticed that even at less than one-quarter load the efficiency is still very satisfactory.

Nearly all of the modern direct-driven generators show this peculiarity in the efficiency curve; namely, the efficiency remains practically constant over a very wide range of loads. In a small machine which is to be run constantly at its full output, this

characteristic of the efficiency curve is not necessary. But in a large machine which is to run for a great part of the time at small loads, it is of the utmost importance that the curve shall show high efficiency, even down to one-eighth of the full output.

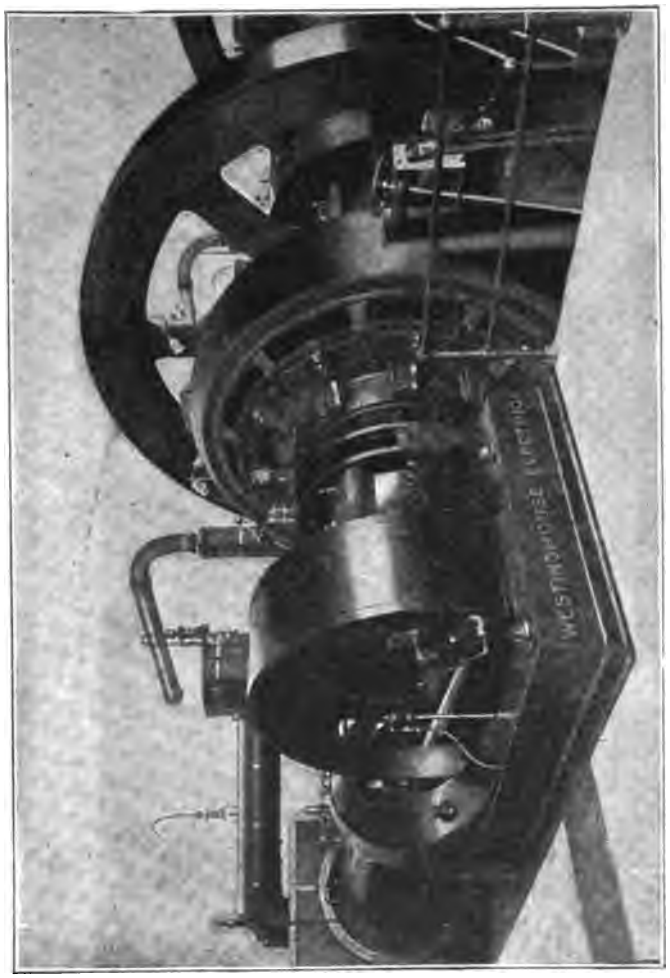
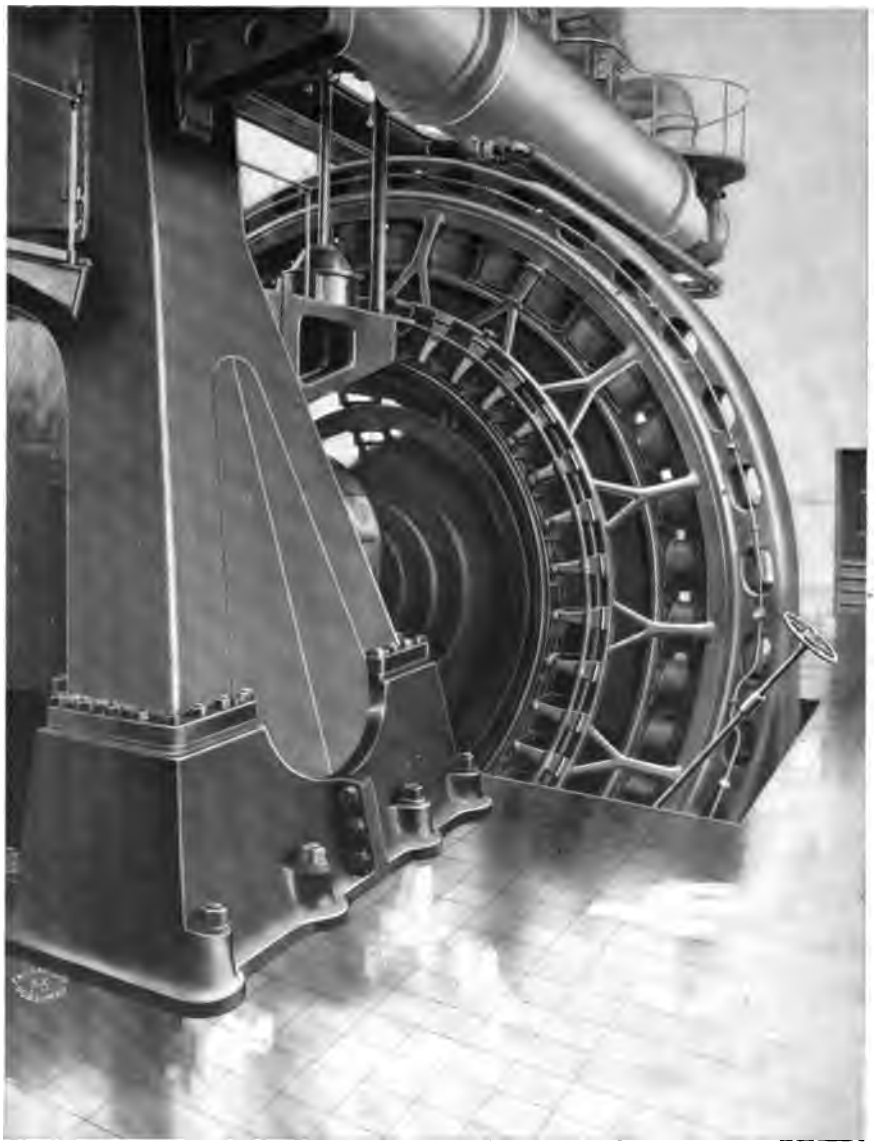



Fig. 12. Westinghouse Railway Generator.

One of the most notable of recent types of electric machinery is the direct-driven lighting and power generator for use on ship-board. Fig. 30 shows a Bullock generator, direct connected to a Forbes vertical steam engine for marine use. In such machinery it is important to reduce the weight as much as is consistent with



**2700 KW. CONTINUOUS CURRENT RAILWAY GENERATOR**
**Built by General Electric Company for Boston Elevated Railway**

safety, and the least possible space must be taken up by the engine and generator. At the same time, it is important that the machinery shall be of the greatest possible durability, as repairs can be made at sea only with great difficulty. The marine generator shows the leading characteristics of the high-grade machines hitherto described, the principal difference being the greater compactness of marine design. The voltage is usually fixed at 110, and the speed ranges from 800 to 400 R. P. M., this latter speed being that of the 22 K. W. size.

Fig. 31 shows the C & C 6-pole engine-type generator. The C & C Company makes machines of this type in standard

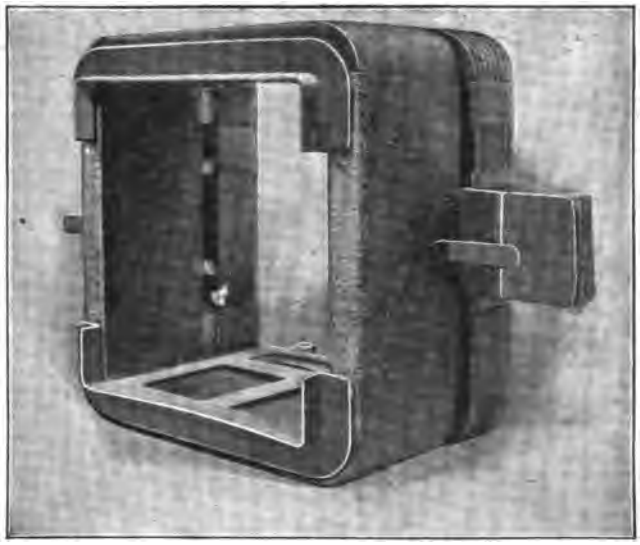


Fig. 13. Westinghouse Compound Field Coil.

sizes of from 25 to 125 K. W., running at speeds of from 325 to 250 R. P. M. The smallest size has 4 poles, and the 125 K. W. size has 8 poles. These generators are not provided with a bed except when specially required. As a rule the generator is mounted directly upon the bed plate of the engine.

The bearings are of the modern self-aligning and self-oiling type. The yoke of the field magnets is of soft steel, the field being cast in two semicircular halves bolted together. The pole

pieces and their shoes are solid castings of steel, their surfaces machined true; they are bolted to the field yoke or ring. The armature spider is strongly built, and its hub is extended into a sleeve which forms a very firm support upon the shaft. The commutator is built up upon this sleeve. The armature core, built up of thin sheets of fine soft steel, is bolted to the spider. This core is slotted to receive the armature windings, and air-ducts are

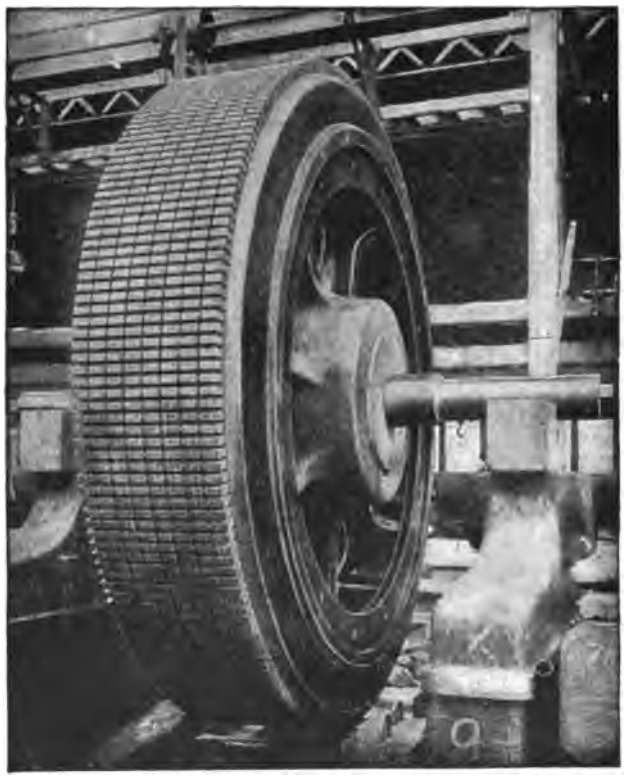


Fig. 14. Core of Westinghouse Armature.

left throughout the core for ventilation. The commutator is made up of rolled copper bars and is very large, giving good wearing qualities.

Fig. 32 shows the **Northern Electrical Mfg. Co.'s** generator, without bearings, for mounting on the shaft of a steam engine. In Fig. 33 the armature core is shown separately. In Northern

machines of large size the field-magnet yoke is cast from soft steel in two pieces bolted together, while in the smaller machines the yoke is cast in a single piece. A special feature is found in the bearings. These are of bronze with an inner spiral lining of Babbitt metal. Should the Babbitt metal through neglect be permitted to heat and run out, the bronze portion of the bearings would continue to support the shaft accurately in position. Another feature of these machines is the armature locking device, by

Fig. 15. Complete Westinghouse Armature with Commutator.

means of which the armature may be mounted quickly and easily upon the shaft of an engine or turbine without tooling either the shaft or the armature bore. It is claimed that with this device the cost and time of erecting the machine is much reduced and that the armature is securely and rigidly locked in place.

The **Thresher** engine-type generator is seen in Fig. 34.

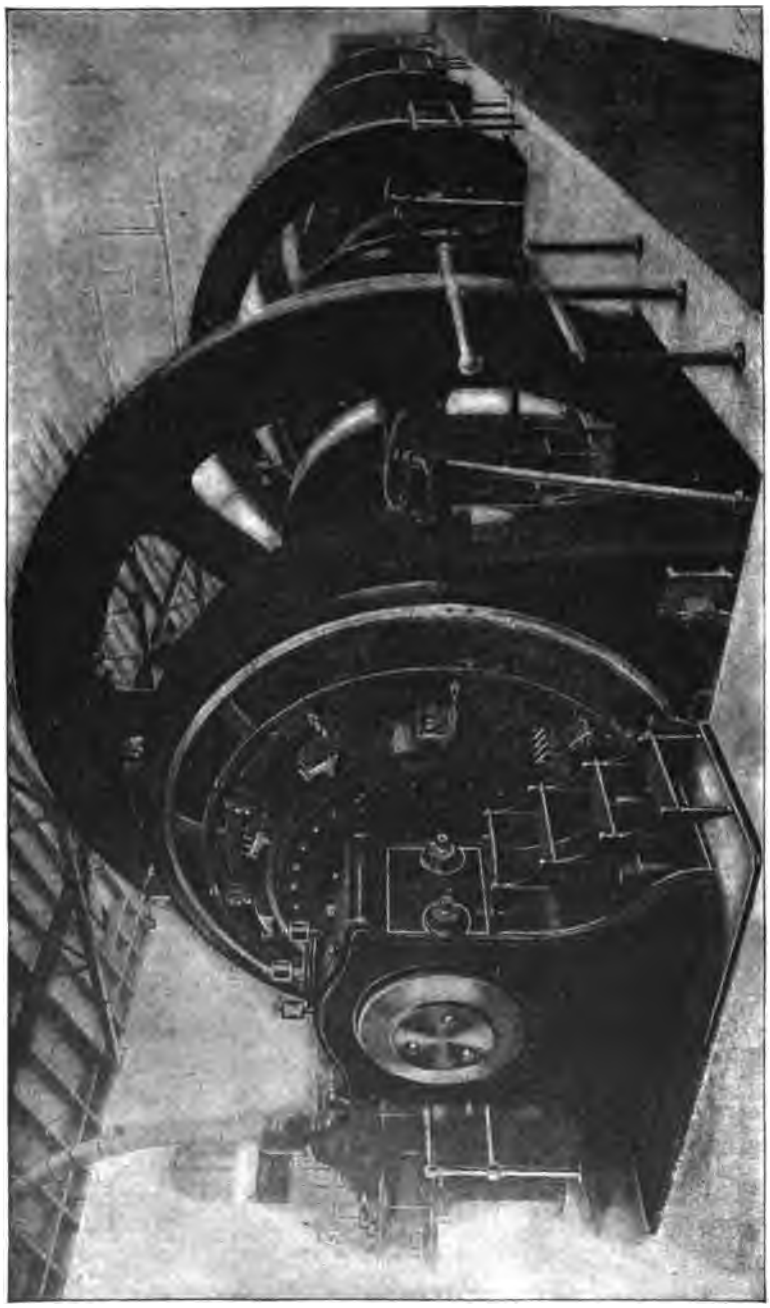


Fig. 16. Group of Westinghouse Generators.

This machine is built in sizes of from 25 K. W. to 400 K. W., running at speeds of from 325 R. P. M., in the small sizes, to 150 R. P. M. in the 400 K. W. size. The field ring is of cast iron, and the pole pieces, finished to fit accurately into recesses in the field ring, are bolted into place. The Thresher Electric Company

Fig. 17. Lundell Generator.

claims that a more evenly balanced magnetic field is secured in this manner than by casting.

## INDIRECT DRIVEN GENERATORS.

Fig. 35 shows a typical **Westinghouse** belt-driven generator for railway service. In this figure the third or "outboard" bearing is clearly shown. Generators of this design are built in sizes of from 100 to 500 K. W., the revolutions per minute rang-

ing from 650 R. M. P. in the smallest size to 320 in the largest. The machine in Fig. 35 is of 500 K. W., while Fig. 36 shows the railway belted generator as designed in sizes of from 100 to 200 K. W. In these machines the third or "outboard" bearing is

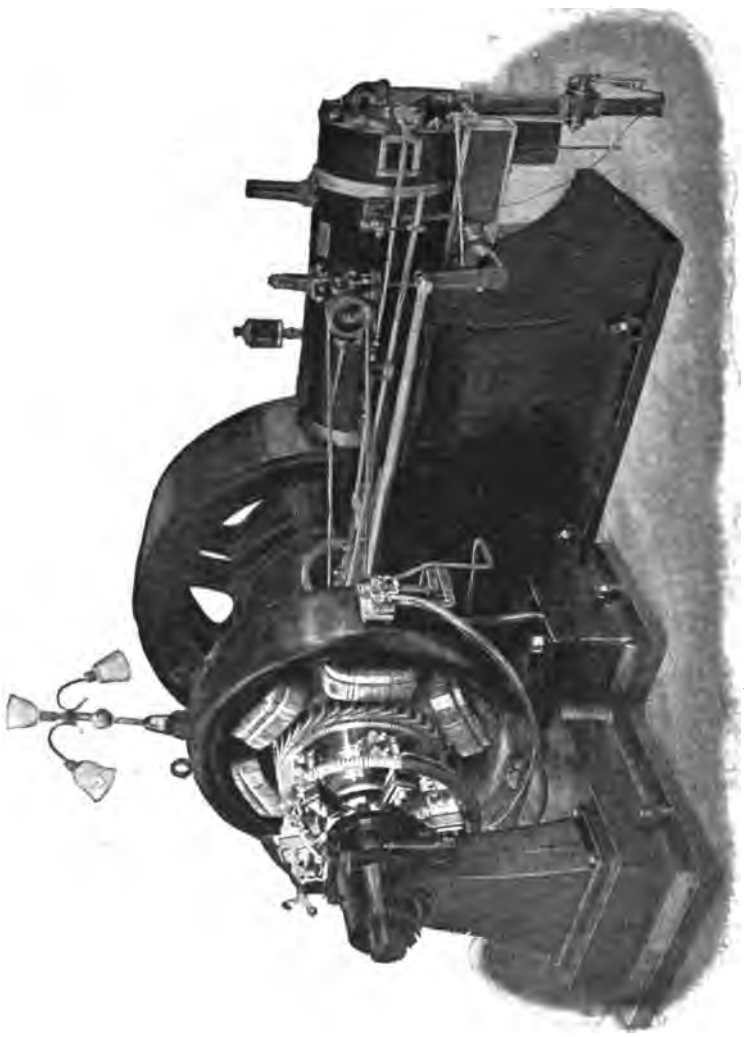


Fig 18 Triumph Generator.

omitted, the pulley being permitted to overhang the bearing, as the belt-pull in these sizes of generator is not severe enough to occasion any difficulty by bending the shaft.

These generators are compound wound, and the winding is so proportioned that the terminal E. M. F. of the machine increases about 10% at constant speed from no load to full load. The armature core is built up of soft steel sheets, and is wound with rectangular shaped copper bars, insulated before placing upon the armature. The coils are sunk in slots in the surface of the armature core and are held in position by wedges. Fig. 37 shows a complete armature for one of the Westinghouse railway generators, and the commutator is shown separately in Fig. 38.

Fig 19. Triumph Generator for Use on Shipboard.

The Westinghouse Company has developed a method by which the potential at all the sets of positive brushes is maintained equal. This is done by equalizer rings as already described. If it were not for these rings, even if the difference of the E. M. F. were very slight, yet owing to the very low resistance of the armature windings a heavy current would flow through the armature windings from one positive brush to another. This would upset the electrical and magnetic balance of the generator and cause wasteful heating of the armature. In fact the machine is far more efficient and more easily regulated when thus modified than

it could be if it were not balanced in some such manner. It would be practically impossible to so design and adjust the generator that precisely equal E.M.F.'s should be generated in corresponding sections of the armature windings.

Furthermore by means of this balancing method the armature

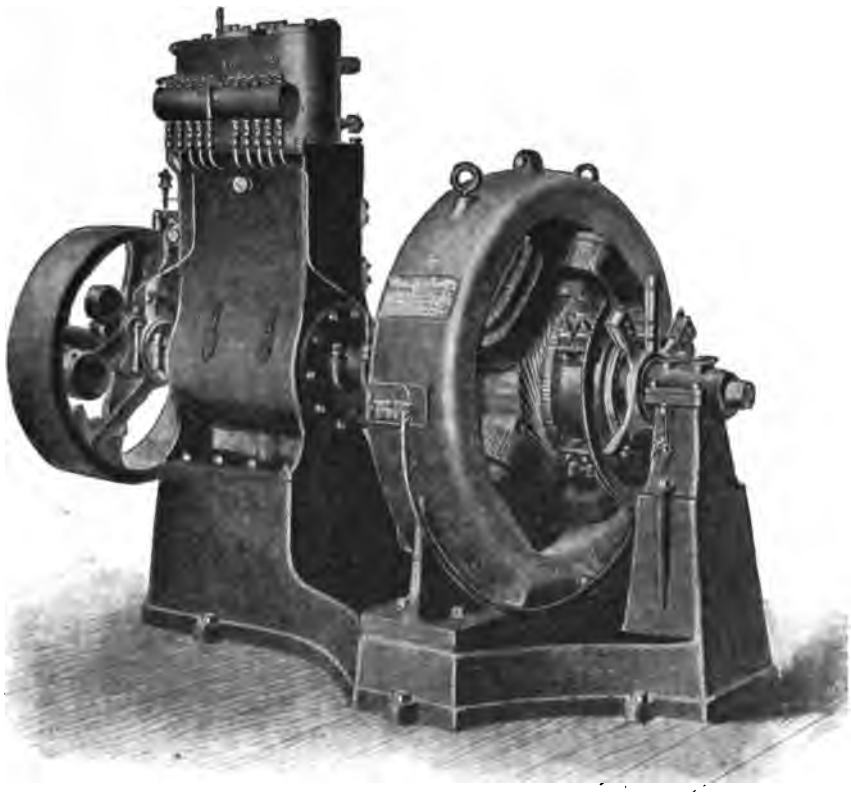


Fig. 20. Large Triumph Generator Mounted on Engine Shaft.

—should it wear slightly out of centre—would still regulate easily, and the efficiency would be maintained.

Fig. 39 shows a Westinghouse belted type of generator as built in small sizes. This machine has no "outboard" bearing, as it is only of 56 K. W. output. The very large surface provided for commutating should be noted. This particular machine is designed for low voltage with a large output of

current. The resistance at the commutator is therefore made as small as possible. A complete armature for this machine is given in Fig. 40.

Fig. 41 shows one of the **General Electric** belt-driven moderate-speed generators. These are made in standard sizes that range from 4-pole 85 K. W. machines with a speed of 750 R. P. M. down to 0.75 K. W. 2-pole machines with a speed of 1200 R. P. M. In a general way, their design suggests the lines of the

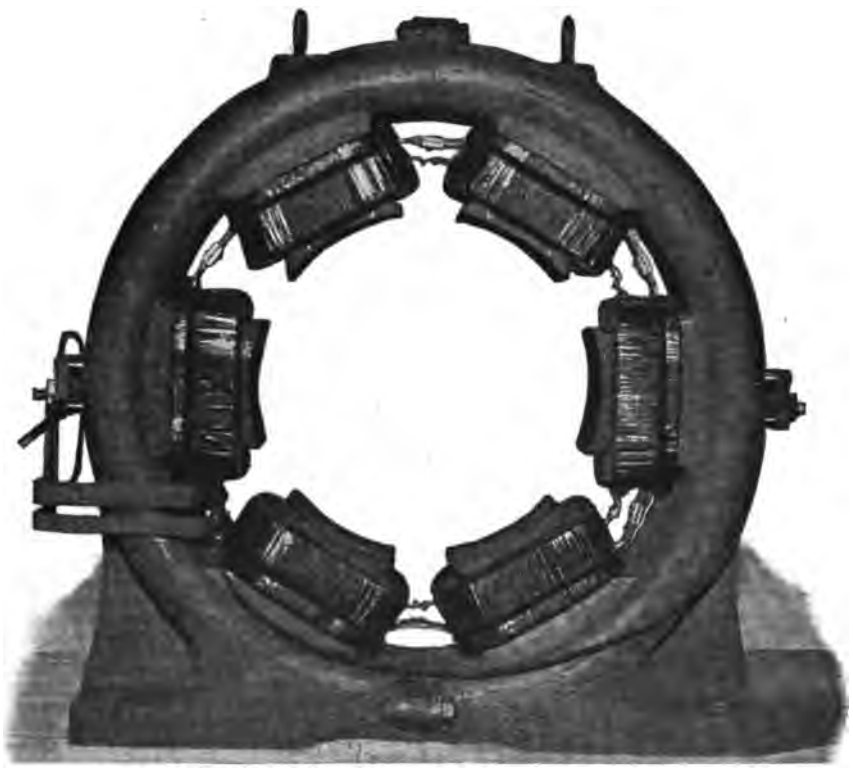


**Fig. 21. Complete Field Frame and Pole Pieces of Triumph Generator.**

direct-driven type. That is to say, the upper and lower halves of the field are cast separately, the lower casting, however, in this case being carried out at the sides to form the lower portions of the main bearings; the pole pieces are bolted into the magnet frame, and the armature is built up of laminated sheet iron, fastened

to a cast-iron spider, this construction permitting of ample ventilation; the armature windings, shown in Fig. 42, are carried in slots cut in the armature core, and the commutator is of large area, ample wearing surface and good ventilation. It will be seen, however, that the armature is of much less diameter and greater length along the axis than in the direct-driven railway machines. Fig. 43 shows the armature in process of construction.

An important feature of these machines is the self-oiling and self-aligning bearing (Fig. 44). In the illustration are seen

Fig. 22. Armature of Triumph Generator.

two loose rings, which hang in a reservoir of oil provided in the lower part of the casting. These rings, rotated by the motion of the shaft, continually bring up a supply of oil.

The rings are, of course, considerably larger than the diameter of the shaft upon which they are hung. There is, however, no friction between them and the shaft. On the other

hand, they cannot get out of place, being confined in position not only by grooves in the circumference of the shaft, but by the upper and lower halves of the case. Oil which is thus enclosed and fed copiously to the shaft may be used with very little wastage for a considerable period of time, and the lubrication secured in this simple and convenient manner is probably more thorough than that obtained in any other way. The shaft not only receives sufficient oil for lubrication, but is, as it were, drenched in oil, which drips continually from it, helping in no small degree to carry away the heat and thus keep the shaft and bearings cool. The oiling of bearings by means of loose rings is now used on a number of the leading types of generators and motors, although a number of our illustrations show oil-cups of the familiar pattern in use upon generator and engine shafts.

Fig. 45 shows the **Crocker-Wheeler** belt-driven generator, looking from the commutator end. In general, these machines conform to the standard type of moderate speed generator. The regular standard sizes range from 200 K. W., operating at 350 R. P. M., down to 9 K. W., operating at 1025 R. P. M. Fig. 46 shows the form of the field magnet frame or yoke, together with the field poles and polar faces. The magnet frame is of cast iron split horizontally, to facilitate assembling and removal in case of injury. The poles are "cast welded" into the magnet frame. That is to say, the poles are constructed first, and are placed accurately in position in the mould in which the field magnet frame is to be cast. The molten metal for the magnet frame flows around the ends of the magnet poles, in this way making a magnetic joint. This method is also a characteristic of some of the Westinghouse machines.

If the "cast-welded joint" is perfectly made, there is no doubt that it will give a better magnetic circuit than would ordinarily be obtained by the method of bolting. There is, however, some difficulty in securing a perfect welding of the metallic surfaces, but this difficulty is now in great part overcome.

Fig. 47 illustrates the **Fort Wayne** belt-driven generator with outboard bearing.

Fig. 48 shows the **C & C Electric Company's** belt-driven generator with overhanging pulley. This generator has 6 poles,

and its general construction resembles that of the engine-type C & C generators previously described. The belt-driven type is made in

Fig. 23. Fort Wayne 50 K. W. Generator.

standard sizes of from 30 to 175 K. W., running at speeds of from 275 to 450 revolutions per minute. The C & C brush holders

are of special patented construction. The carbon brushes are inclined at a slight angle from the radial line, and it is claimed that with this design of brush the direction of rotation of the armature may be changed without altering the position of the brushes and without sparking.

Fig. 49 shows the **Bullock** belted generator of the multipolar direct current type. The massive construction of the

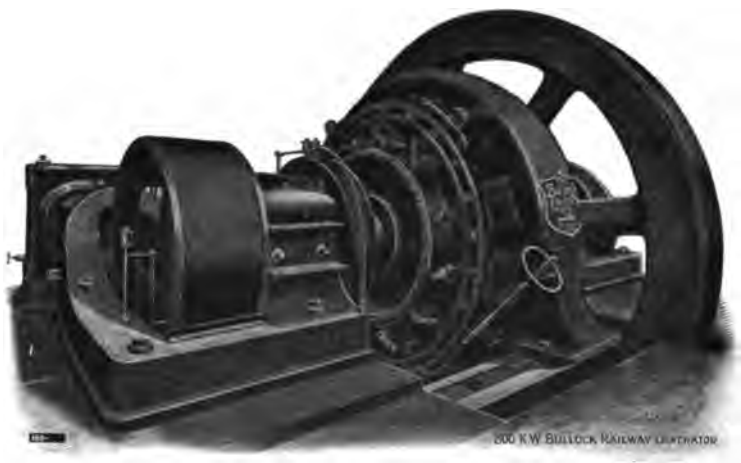


Fig. 24. Eight Hundred K. W. Bullock Generator.

machine is evident. A feature of special interest is the enormous belt pulley provided. This pulley is carried by the shaft between one of the main bearings of the generator and a third or "outboard" bearing. The base plate of the generator rests upon three rails or sub-bases of cast iron, and the belt is adjusted by sliding the machine bodily along these rails by means of the adjusting levers shown. These levers are connected together by a bar, and are worked by a ratchet gear, which insures that both ends of the machine shall be moved through equal distances.

Fig. 50 shows the belted multipolar generator made by the **Western Electric Co.**, and Fig. 51 shows a similar machine by the same company. The bipolar machines are made up to 3 K. W., and the regular multipolar machines of the type shown

run up to 250 K. W. The lower half of the frame of the multipolar machines, together with the base and the pedestals, are in one casting, while the upper half of the frame is also a single casting. In the smaller machines the frame is cast in a single piece. Slide rails are used, and the belt is tightened by means of the chain and ratchet.

The armature is of the iron-clad type, having bare conduct-

Fig. 25. Spider for Bullock Armature.

ors imbedded in insulating tubes below the surface of the core, no band wires being used. The insulating tubes are made up of alternate layers of pressboard, oil-paper and mica. The armatures are stated to be perfectly balanced both mechanically and electrically, so that they will operate without vibration. Provision is made for ventilation in the usual manner by the use of air-ducts through the armature core.

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tice, and is calculated in amperes per square inch of cross-section of conductor. Thus armature conductors as ordinarily calculated carry 2,000 to 3,000 amperes per square inch of cross-section. For instance a, round armature wire one-half inch in diameter will carry 392 to 589 amperes, and so on.

Similarly in figuring commutator capacity a definite figure must be fixed for the amount of current to be carried per square inch of cross-section of commutator segment. A figure must also be determined for the current carried per square inch of surface of the brushes where the brushes make contact with

**Fig. 27. Eight Hundred K. W. Bullock Generator Disconnected from Engine.**

the commutator. These figures vary somewhat among the different manufacturers. In the Holtzer-Cabot machines the carbon brushes are designed to carry 25 amperes per square inch of cross-section when the machine is carrying full load. Copper brushes may carry 175 amperes per square inch of contact surface. This is conservative design, and provides such ample surfaces of contact that the commutator is certain to run without heating at all loads.

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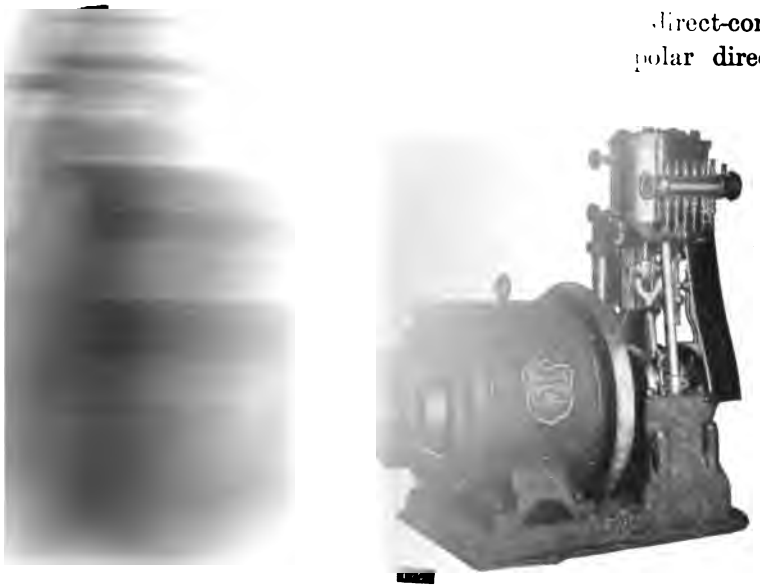


Fig. 30. Bullock Generator for Use on Shipboard.

a low E. M. F., but having a very large output in
In fact, the current is so great and the E. M. F so
hat it is necessary to take extraordinary precautions to
own the resistance at the commutator. It will be seen that
rmature carries two commutators, each of very large area
ted with an unusual number of brushes. There is only
armature winding, the two commutators being therefore in
allel. That is to say, an armature coil at the point of tapping
is connected by massive connecting bars to a segment of each
mmutator. The two sets of brushes are regulated independ-
tly by means of the two hand-wheels seen in the illustration.

sliding the generator forward or back upon the rails, thus tightening or slackening the belt. The ratchets by which this is accomplished are seen in the illustration coupled together to

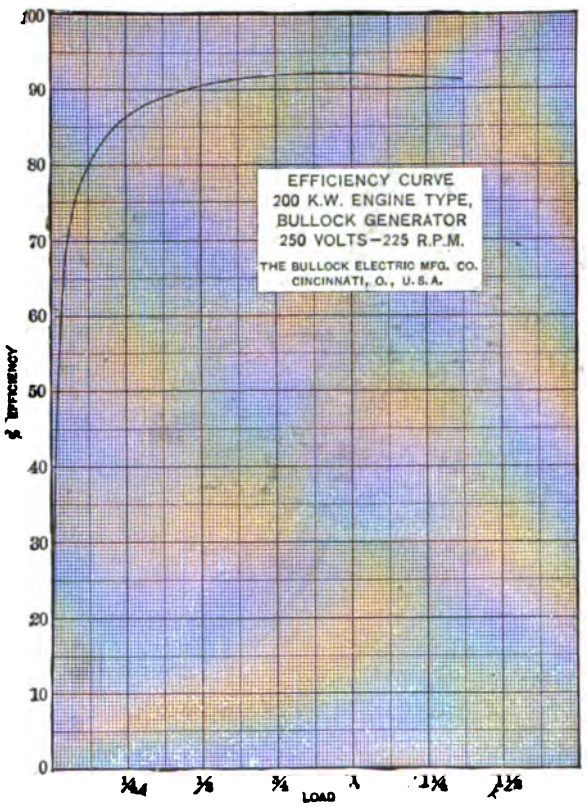



Fig. 29. Efficiency Curve of 200 K. W. Bullock Generator.

insure equal motion of both ends of the generator base, and a lever for manipulating the ratchet gear is also seen.

## GENERATORS FOR ELECTROLYTIC WORK.

Generators for electrolytic work have recently been developed to a high degree of mechanical and electrical excellence. In treating of the "Elements of Electricity" we discussed the general principles involved in electrolysis. In commercial electrolytic work (such as electrotyping, electroplating and many

chemical manufactures) a very powerful current flowing at a low electromotive force is needed as a rule. Electrolytic generators accordingly are required to give an extremely low E. M. F., since any E. M. F. in excess of that required for the electrolytic bath would be wasted, having to be absorbed by series resistances. Only a slight surplus E. M. F. is provided for regulation of the current.

Fig. 61 shows the **Westinghouse** direct-connected generator for electrolytic work. It is a multipolar direct current gener-

Fig. 30. Bullock Generator for Use on Shipboard.

ator giving a low E. M. F., but having a very large output in amperes. In fact, the current is so great and the E. M. F so small that it is necessary to take extraordinary precautions to keep down the resistance at the commutator. It will be seen that the armature carries two commutators, each of very large area and fitted with an unusual number of brushes. There is only one armature winding, the two commutators being therefore in parallel. That is to say, an armature coil at the point of tapping off is connected by massive connecting bars to a segment of each commutator. The two sets of brushes are regulated independently by means of the two hand-wheels seen in the illustration.

The circuits derived from the two commutators may be separately applied to outside work or may be united in simple parallel.

Fig. 62 shows the armature with double commutator for a Westinghouse electrolytic generator. The generator illustrated is shunt wound, with an output of 4000 amperes.

## ARC LIGHTING GENERATORS.

Arc lamps are in many cases supplied by an alternating current of high potential. This method will no doubt continue in very general use, but installations of arc lamps are now very common on direct current circuits of both high and low potential. On low potential circuits two arc lamps are often run in series (as, for example, from a 110-volt circuit). Thus 100 lamps would be connected up in 50 parallel rows, each row containing two lamps in series. On high potential direct current circuits the lamps are all in series, or else there are several parallel rows of lamps, each row having a considerable number of lamps in series. This latter arrangement, modified, is explained more fully in discussing the General Electric arc lighting generator.

Fig. 31. C & C Engine-Type Generator.

High potential direct current arc lighting generators are manufactured by several prominent companies, and we give a few leading types.

Fig. 63 shows the **Westinghouse** direct current high potential arc lighting generator designed for belt driving, for 75 arc lights. In general construction it resembles the other Westinghouse multipolar generators and like them has self-oiling and self-aligning bearings. The machine illustrated operates at 825 R. P. M., giving 6.8 amperes at 3750 volts.

The generator is of the open coil type giving a current which, while constant in direction, is not absolutely continuous. The result is a pulsating current which causes a very slight vibration of the feed mechanism of the lamps. This prevents sticking of

**Fig. 32. Northern Electrical Mfg. Co.'s Multipolar Generator.**

the feed, but is far too slight to effect the steady, uniform intensity of the light. In Fig. 64 is shown the armature partially wound. The coils are being forced into position upon the laminated and slotted armature core. The complete armature is shown in Fig. 65. The commutator for the open coil winding is seen at the extreme right; and at the extreme left, as also between the armature and commutator, are seen loose rings hanging from the

Fig. 33. Armature Core of Northern Generator.

shaft. These are the rings which dip into the reservoirs of oil provided for in the bearings. As the rings rotate with the shaft they continually draw up a fresh supply of oil, thus keeping the bearings thoroughly drenched.

The Westinghouse direct current arc lighting generator is excited by means of a small direct current machine furnishing a 100-volt current. This practice frees the field windings from the chances of grounding and makes the handling of the machine much safer. A feature of these machines is that the armature coils are easily removed and replaced. It is not necessary there-

**Fig. 34. Thresher Engine-Type Generator.**

fore to keep on hand an extra armature, since an injured coil may conveniently be removed and a fresh one substituted.

The **General Electric** direct current arc lighting generator appears in Fig. 66. This is a modern development of the historical Brush generator and is of the same general type embodying

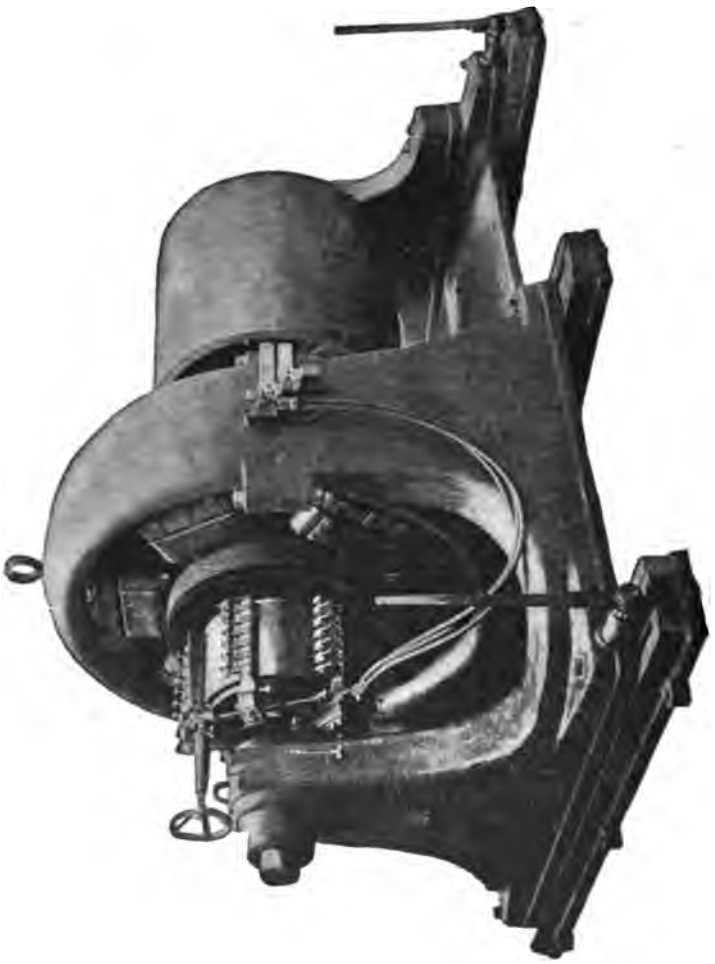


Fig. 35. Westinghouse Belt-Driven Generator.

the same general principles. The modern machines however, in distinction from earlier types, operate on the "multi-circuit" arrangement. Upon the shaft of the armature are mounted a

number of separate commutators, each properly connected to the armature windings and supplying separate groups of lamps on

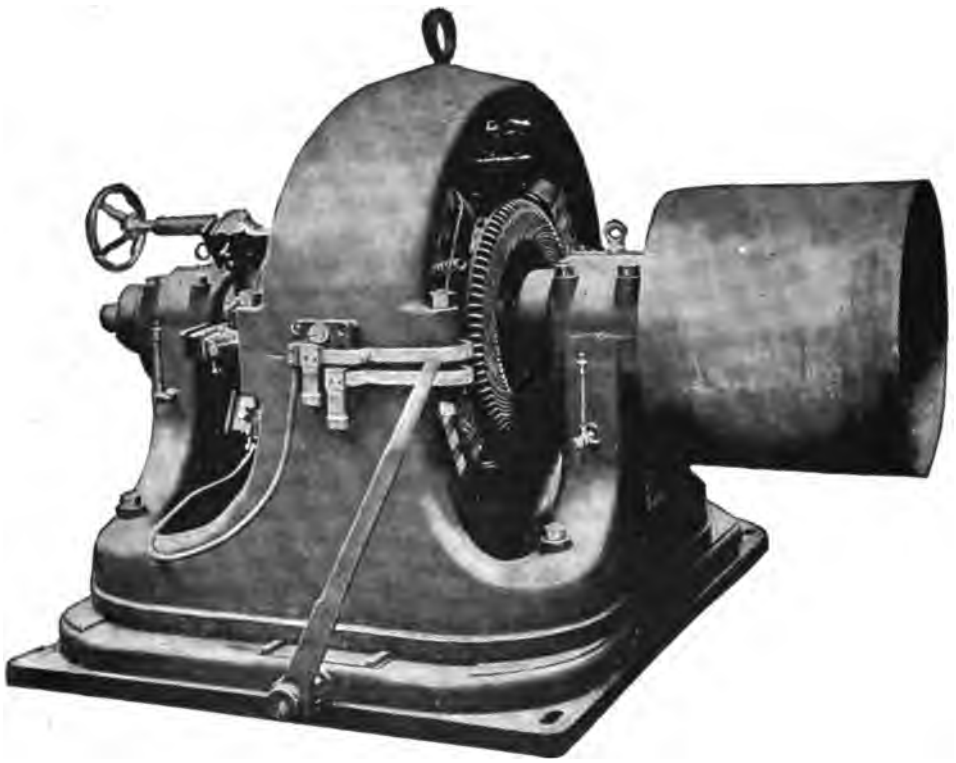


Fig. 36. Westinghouse Belt-Driven Railway Generator.

Fig. 37. Armature of Westinghouse Generator.

separate mains. Nearly 100,000 arc lights are now supplied by large-size General Electric generators of this type.

Fig. 38. Westinghouse Commutator.

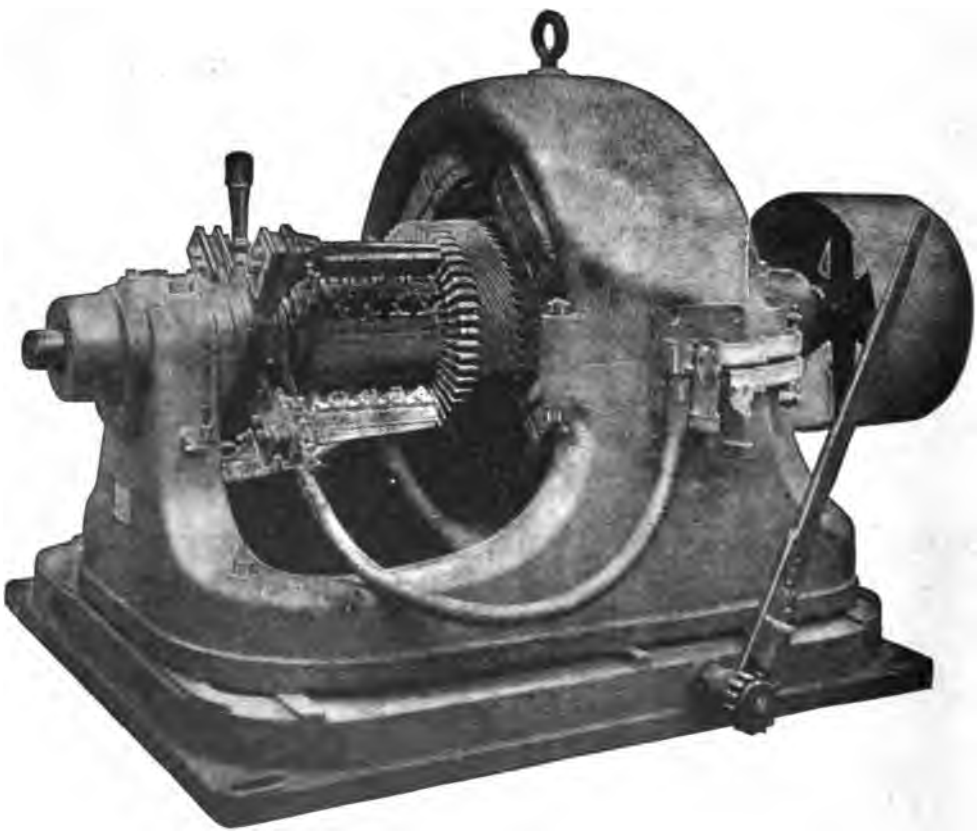


Fig. 39. Westinghouse Belt-Driven Generator, 56 K.W., for Electrolytic Work.

The student will have seen from the foregoing pages that the modern types of generator are more and more tending to large size; and the same is true, though to a less extent, in regard to motors. The designs now in hand by the larger electrical companies indicate that the next few years will see dynamo-electric

Fig. 40. Westinghouse Armature for Electrolytic Work.

machines of still larger dimensions. In fact, it is difficult to see at present any practical limits to the size of the electric generator.

This growth in size as well as in numbers is due to numerous causes. The increased demand for electric energy has, of course,

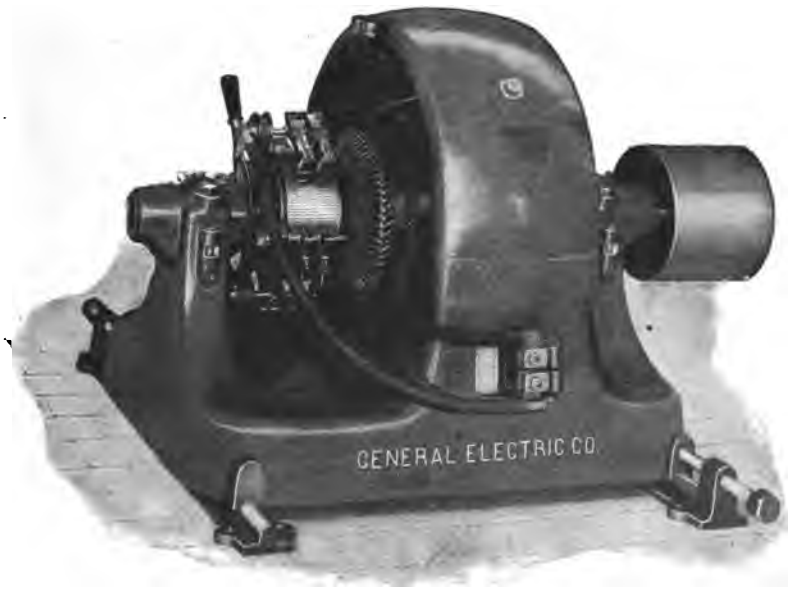



Fig. 41. General Electric Co.'s Belt-Driven Generator.

had an influence on the design of the large modern machines. Also there is a greatly increased economy of construction in equipping a plant with a few large machines in place of a large number of smaller units. Obviously, in designing a station the engineers

Fig. 42. General Electric Armature.

endeavor to plan the installation so that the generators shall run during a large part of the time at or near full load. This is done because the generator works at better efficiency when at or near full load. Hence, as the demand for electric energy increases, generators of larger size are built. Commercial machines, running at their full output, and necessarily tending to become

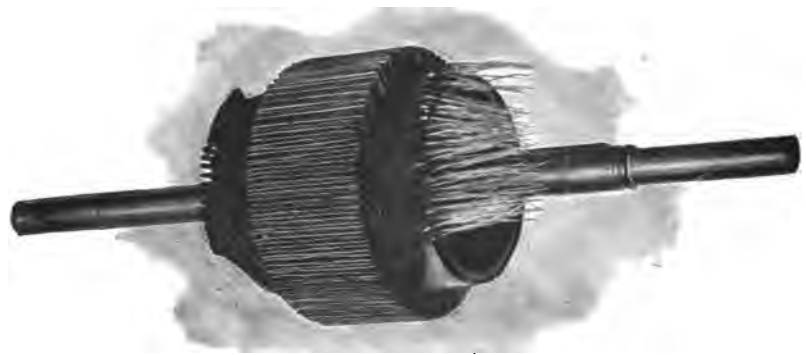


Fig. 43. General Electric Armature, Unfinished.

Fig. 44. General Electric Self-Oiling Bearing.

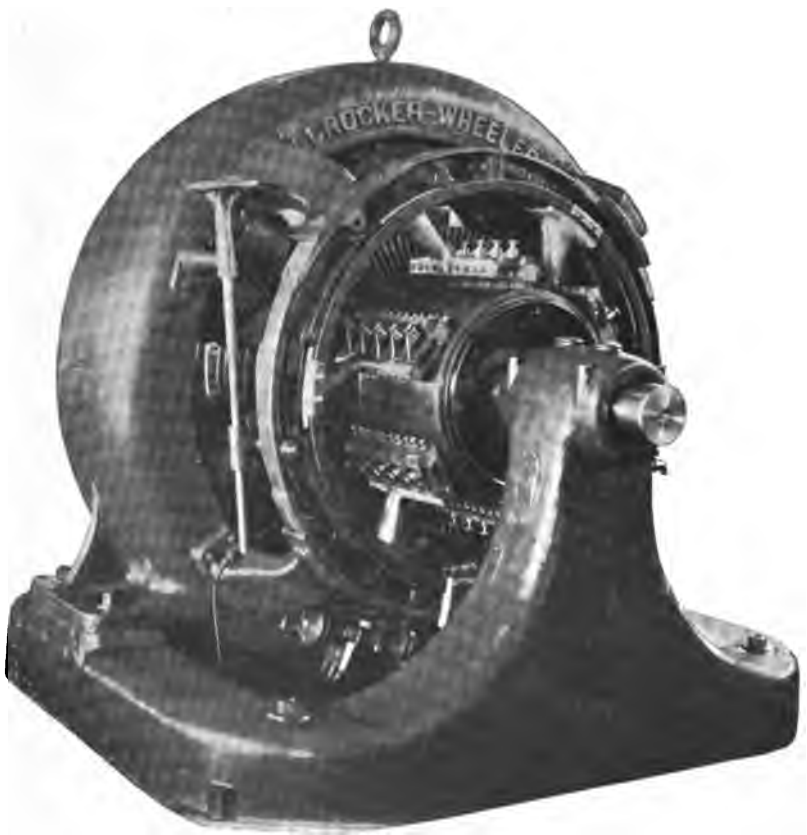



Fig. 45. Crocker-Wheeler Belt-Driven Generator.

heated, require unusual facilities for ventilation, and such ventilation can only be secured by a design which affords massive metallic bodies for conducting and radiating away the heat generated, and in which ample air spaces are left. The student will see in the following pages that these same considerations have held in the case of the electric motor, but to a considerably less

Fig. 46. Yoke and Poles of Crocker-Wheeler Generator.

degree, inasmuch as the conditions under which motors and generators operate are so different.

The direct current generator and motor have hitherto held the foremost place in electrical supply systems, and they are continually being improved in design and construction, so that every year adds something to their efficiency and mechanical excellence. Although direct current machines are becoming higher and higher in grade, they are no longer foremost in the electrical world.

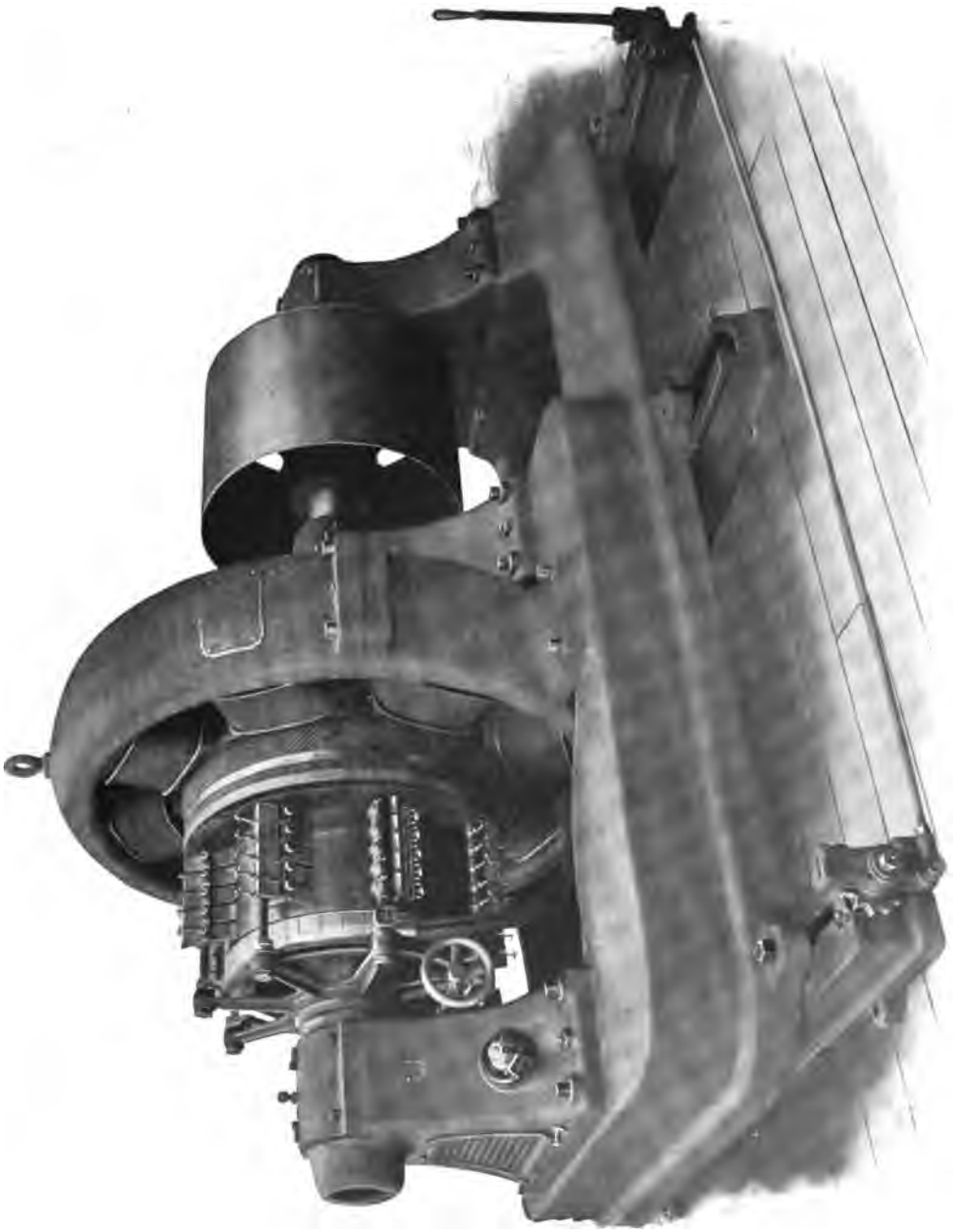


Fig. 47. Fort Wayne Belt-Driven Generator.

Within the last five years the alternating current motor has developed so rapidly that it is now a practical and reliable piece

Fig. 48. C & C Electric Co.'s Belt-Driven Generator.

of apparatus, and is coming very rapidly into use for a great variety of applications. Therefore, in studying the present Paper the student should bear in mind that the types here shown, although they are growing in size and number every year, are not

Fig. 49. Bullock Belt-Driven Generator.

holding their own against the newer system of polyphase electric transmission. The polyphase current systems are described in subsequent Papers, and the student will do well to give them careful attention. The alternating current is better adapted to long distance transmission, because it can be conveniently generated and transmitted at far higher voltages than are ordinarily possible in direct current work. And, of course, the use of a high voltage permits the use of smaller currents for transmitting

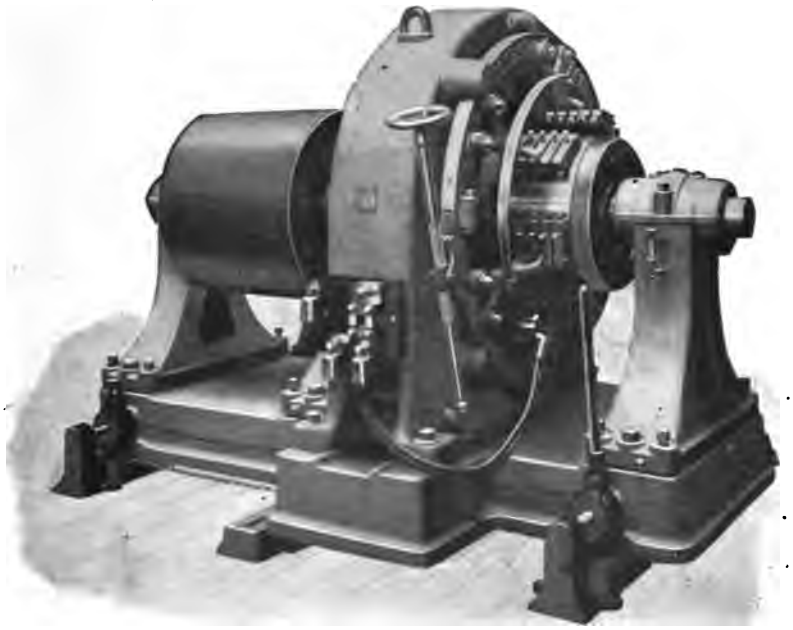


Fig. 50. Western Electric Co.'s Belt-Driven Bipolar Generator.

a given amount of energy. There are, however, many classes of service in which the direct current is preferable, and in which it will, no doubt, continue to be used for many years to come. Such classes of service are, for example, the supplying of power to small consumers in the immediate neighborhood of the generating station, and the operation of electric cars. The student must bear in mind the limitations of the direct current system, in order that he may be able to choose intelligently between the two. He should give the preference to the direct current system whenever the conditions seem to justify such choice, because of the greater

convenience, safety and simplicity of a direct current installation, but he should adopt the alternating current system when the transmission of a direct current would be marked by undue losses in the transmission line. We shall go more fully into the characteristics of alternating current work in subsequent papers. At present the student should make himself thoroughly familiar with the direct current methods as a basis for subsequent study of alternating current machinery.

Fig. 51. Western Multipolar Generator.

The following portion of this Paper is devoted to a discussion of Direct Current Motors, the motors being grouped under a separate heading, in order that they may be better compared with one another. It should be borne in mind, however, that the essential difference between a motor and a generator is slight. Of the motors illustrated here, practically any one may be driven

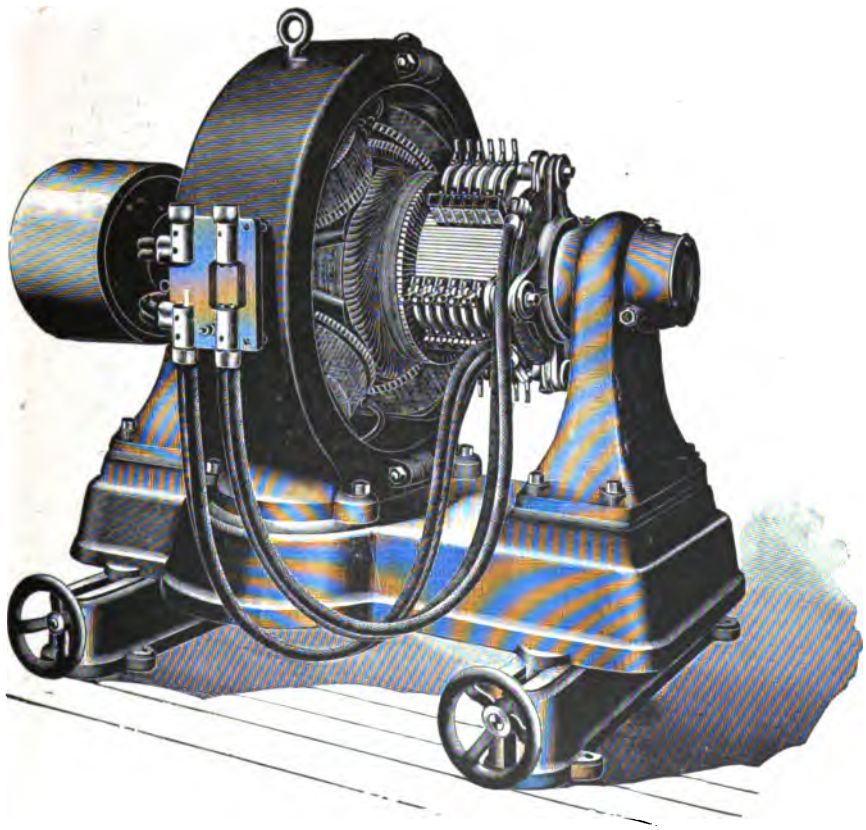


Fig. 52. Holtzer-Cabot Belt-Driven Generator.

as a generator by some outside source of power. It will then give out a current corresponding in quantity and voltage to that supplied to it when running as a motor, provided the conditions are kept constant and the same speed is maintained.

The principal difference between the two cases would be a readjustment of the brushes to suit the changed direction of rota-

Fig. 53. Detail Parts, Holtzer-Cabot Generator.

Fig. 54. Holtzer-Cabot Armature.

Fig. 55. Holtzer-Cabot Armature Core.

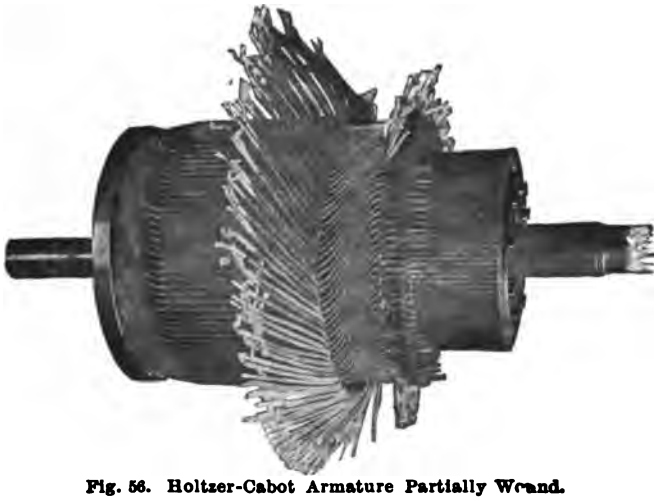


Fig. 56. Holtzer-Cabot Armature Partially Wound.

Fig. 57. Holtzer-Cabot Commutator.

tion, or a different connection to the outside circuit. In fact, some of the machines which are shown in the following pages are put upon the market not only as motors, but as generators. In

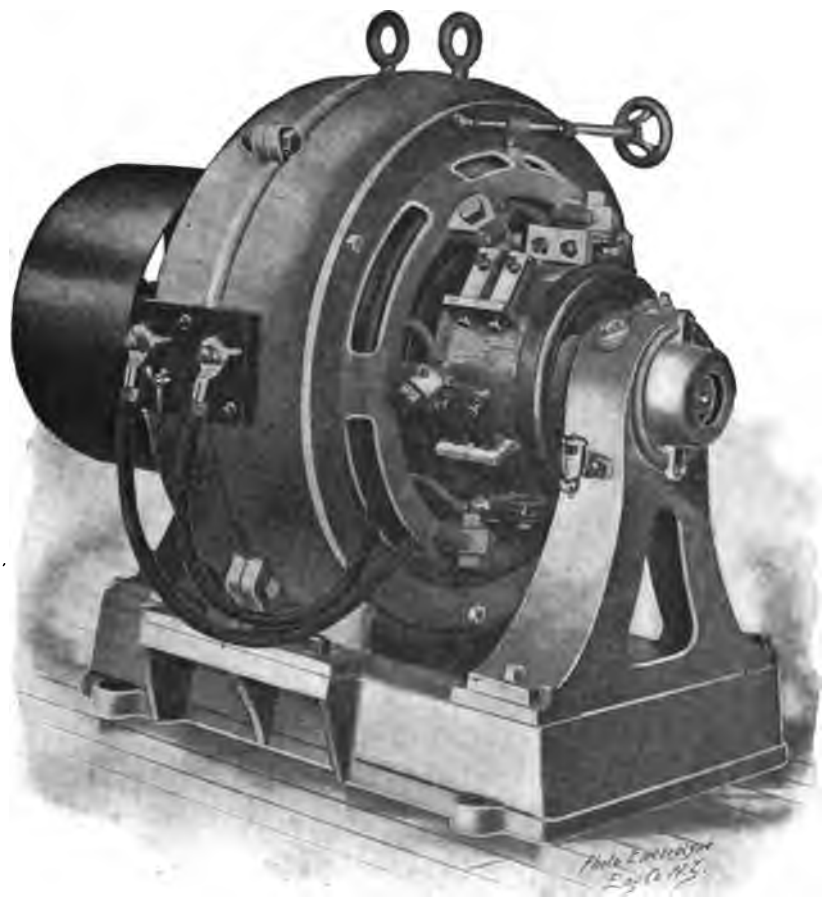


Fig. 58. Lundell Belt-Driven Generator.

most instances, however, the generator is designed for adjustment to a rigid base, whereas motors are frequently used on cars, cranes, or for other nonstationary applications.

Also, the ordinary motor is smaller in size than the average generator, since for economy in supply it is customary to design

one generator to furnish current for a large number of motors. In fact, this is one of the principal considerations which determine the difference in design between generators and motors.

The generator, being usually built for continuous running, requires ample ventilating area, whereas some types of motor are

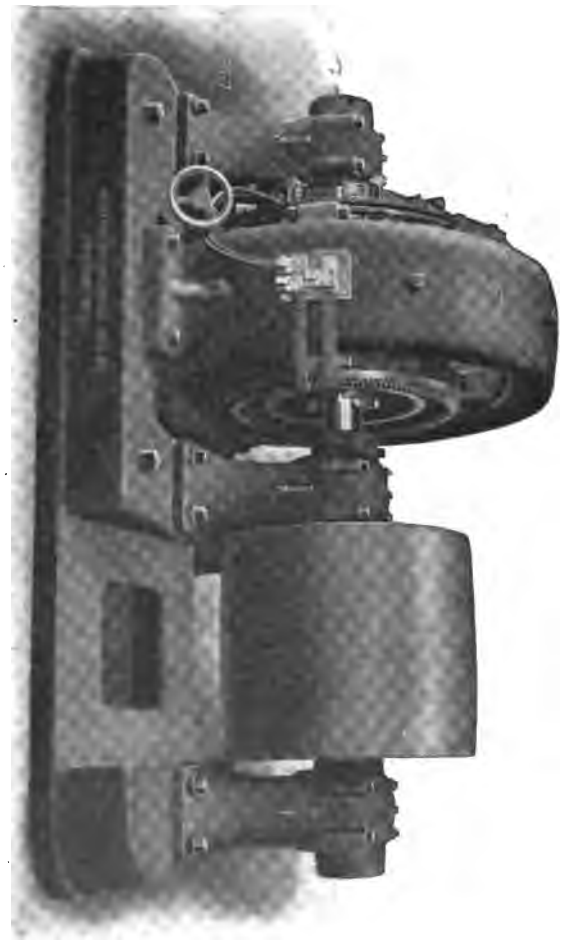


Fig. 59. Northern Bell-Driven Generator.

designed for intermittent running, and ventilation is comparatively unimportant. All motors for shop use should be so designed that they may be readily transferred from one position to another, and should have a range of speeds that would not be necessary in a generator.

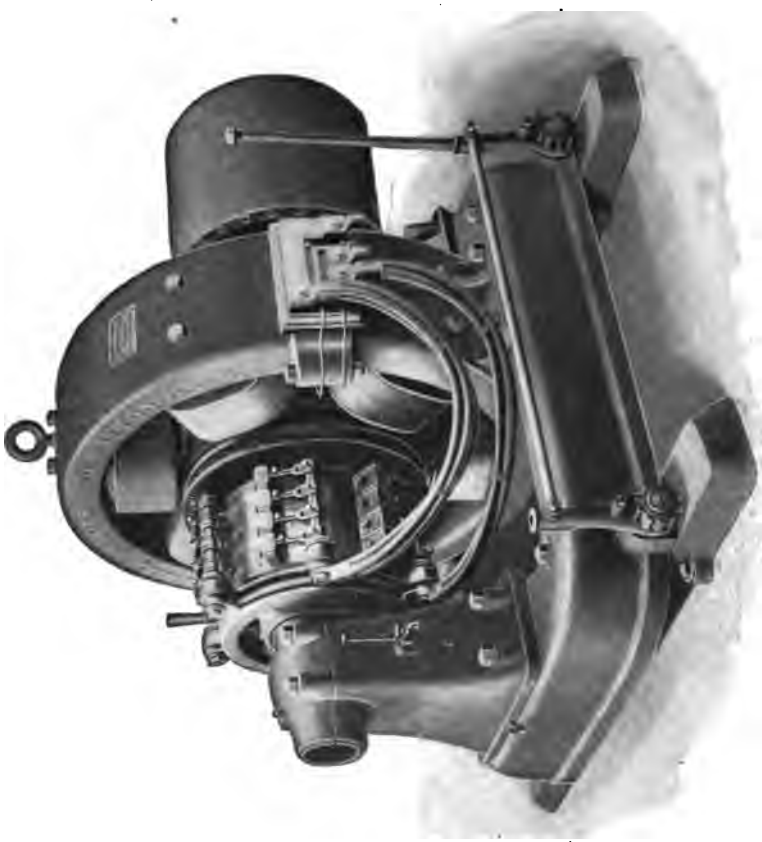


Fig. 60. Thresher Belt-Driven Generator.

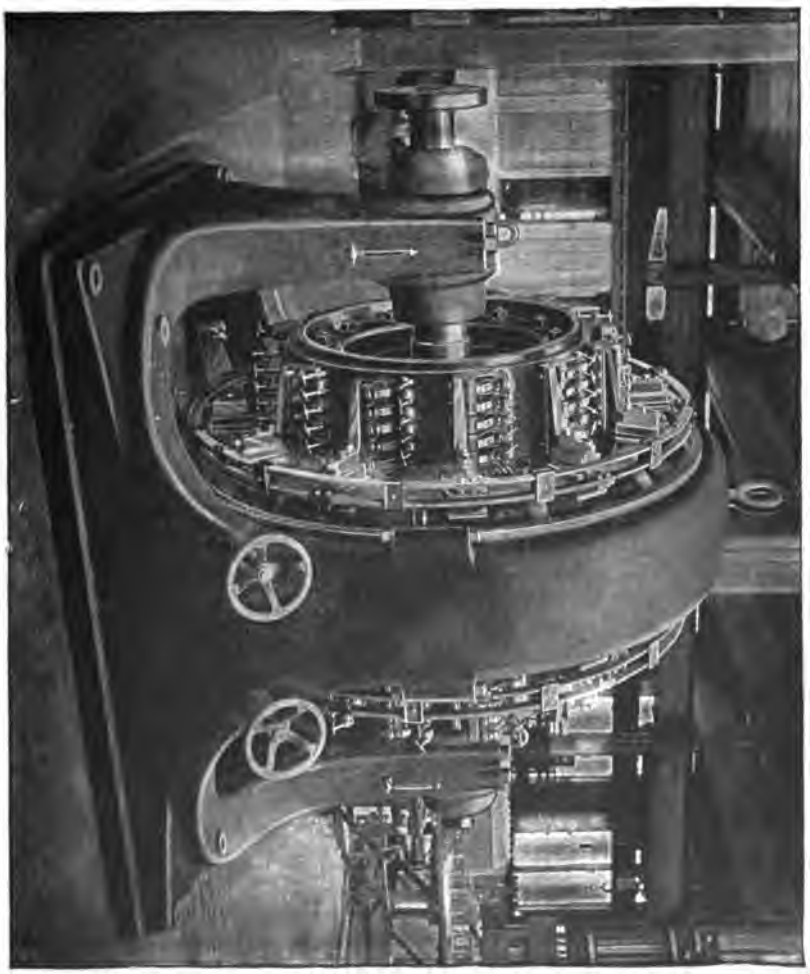


Fig. 61. Westinghouse Direct Current Generator with Two Commutators for Electrolytic Work.

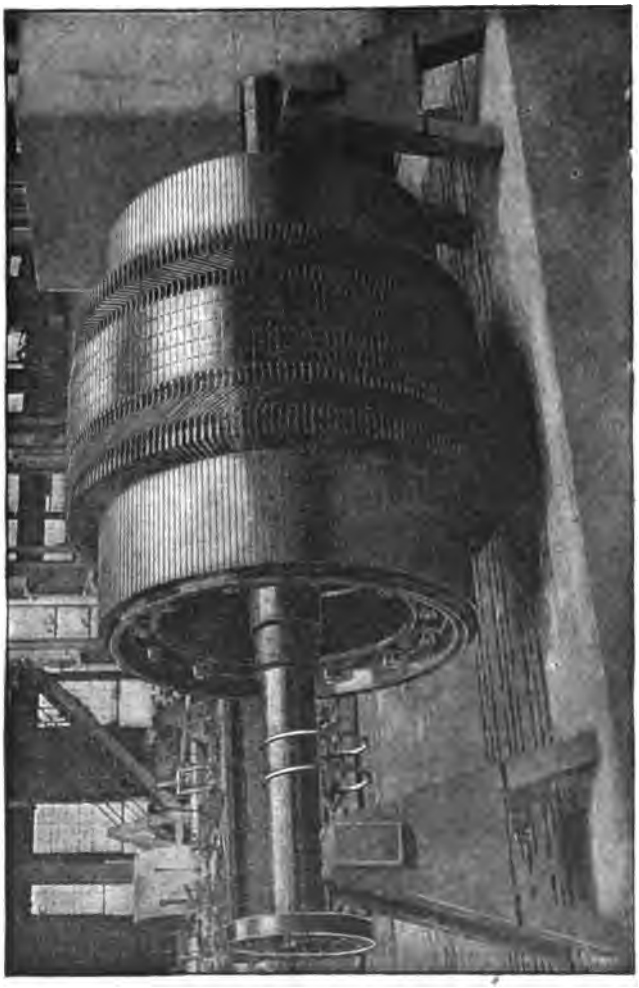


Fig. 62. Westinghouse Armature with Two Commutators for Electrolytic Work.

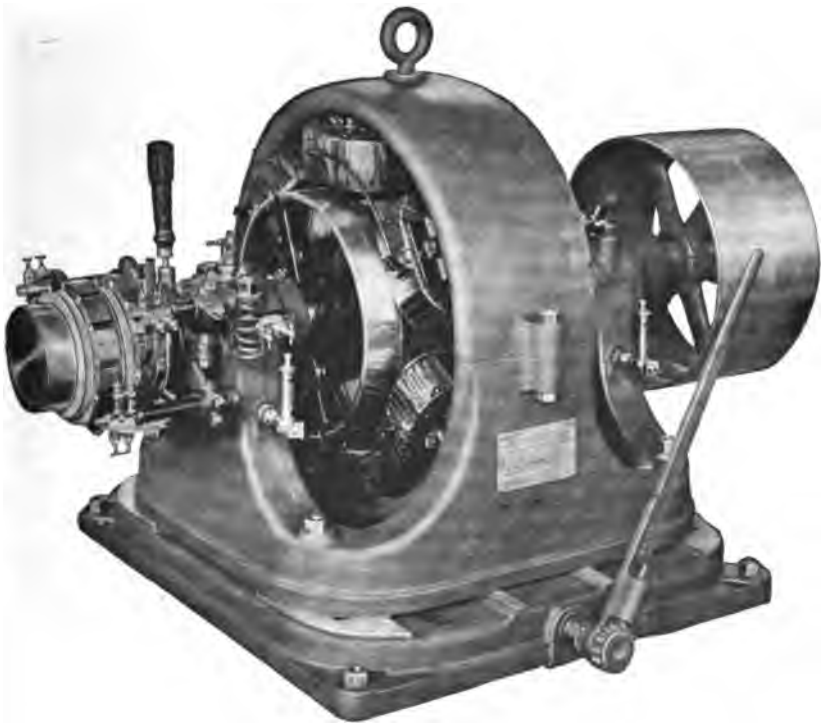


Fig. 63. Westinghouse Direct Current High Potential Arc Lighting Generator.

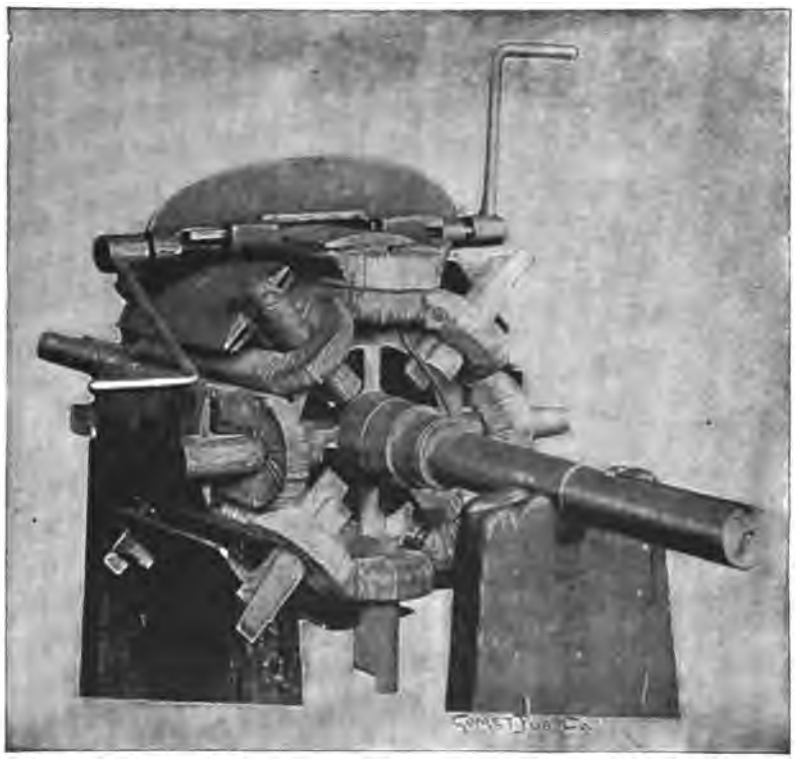


**Fig. 64. Armature of Westinghouse Arc Lighting Generator Partially Wound.**

Fig. 65. Complete Westinghouse Armature of Arc Lighting Generator.

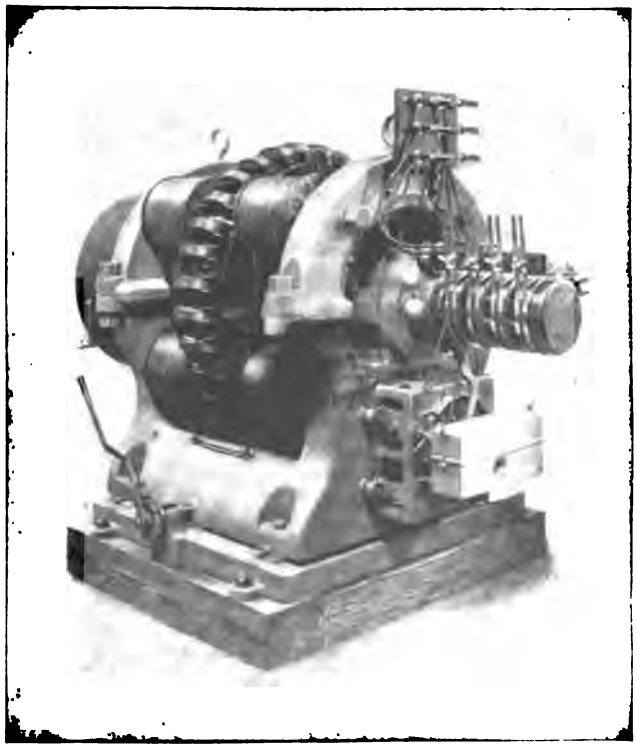


Fig. 66. General Electric Arc Lighting Generator.

## DIRECT CURRENT MOTORS.

Many characteristic features of the engine-type and direct-driven direct current generators are now commonly followed in designing direct current motors. Formerly the leading types of

Fig. 67. Direct-Connected Crocker-Wheeler Motor in Testing Frame.

motor were, generally speaking, of high speed and had to be belted to the machinery which they drove. Representative manufacturers, however, now favor the direct method of driving. The 2-pole motor is giving way to the multipolar type, and the high speed

is being superseded by speeds of from 300 to 800 R. P. M. In some instances even lower speeds than 300 are used.

Slow-speed motors for direct driving are now commonly mounted upon the shafts of lathes, boring mills, drill presses, shapers, punching machinery, hydrostatic presses, laundry machinery, traveling cranes, pumps, printing presses, mine hoists and many other classes of machinery.

When a machine is driven by a direct-connected motor it may be placed in the most convenient position for operating, whereas

Fig. 68. Crocker-Wheeler Dust-Proof Mill Motor.

machinery driven by line shafting has to be placed in positions determined partly by the shafting. Shafting is entirely done away with in plants where all the machinery is direct driven by motors. Many prominent printing plants are now operated by motors direct connected to the presses, and this system of direct driving is being applied to a large percentage of the great mills, factories and steel works.

The absence of shafting and belting in a mill is a great advantage, as belts and shafts interfere with the lighting and ventilating of the premises and are dirty, noisy and cumbersome. Moreover, in many plants a very large percentage of the total power is wasted in driving the shafting. In some plants having

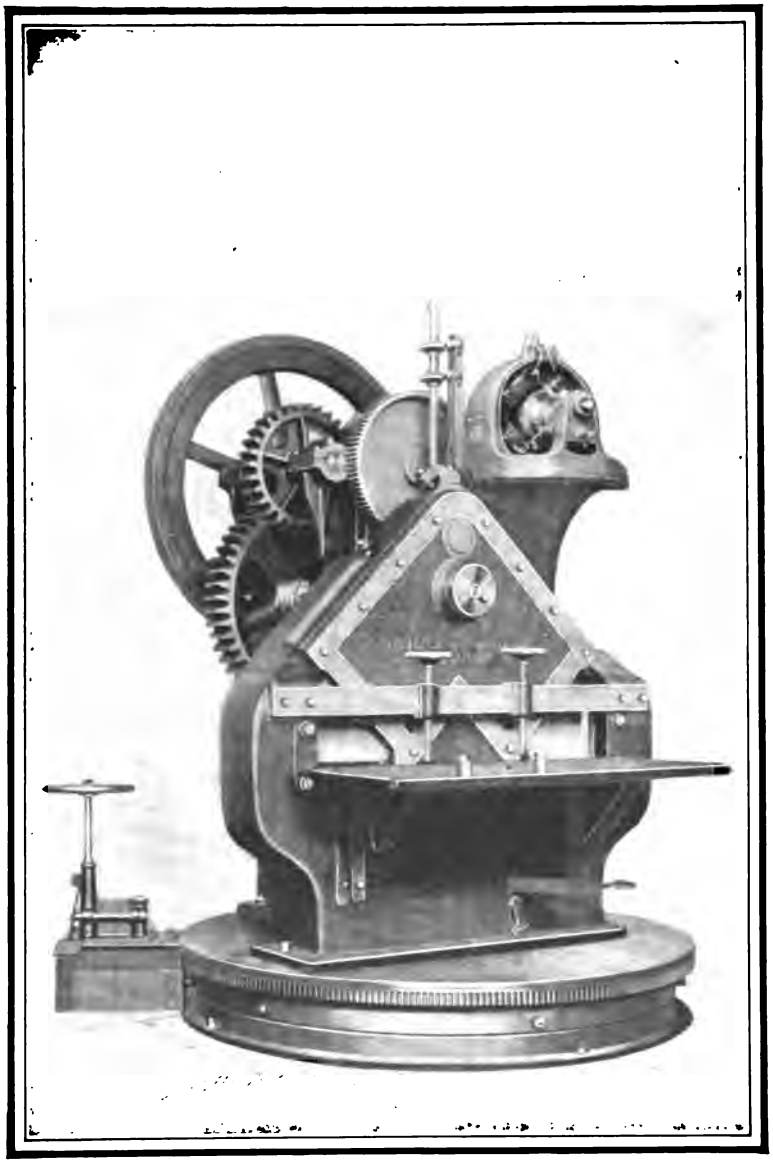


Fig. 69. Westinghouse Multipolar Motor Operating Shears.

an unusually great amount of belting it is said that 75% of the output of the driving engines is probably lost in the shafting, countershafting and belting, only about 25% being left for driving the machinery.

In plants driven by motors attached directly to the various machine tools there is a very great gain in cleanliness and in attractive working conditions. The control of the various machines is far better and the plant is operated with much less noise. Instead of having from 25 to 50% only of the output of the steam engines available for operating the machinery, with a well-built electric equipment over 75% of the total power is delivered at the shafts of the machine tools.

On the other hand, the cost of installing electric motors is at all times a considerable item, particularly where a large number of small motors are used. This expense is increased when multipolar slow-speed motors are used, as motors of slow-speed type are usually much more massive and expensive than the old-fashioned, compact, high-speed motors. So it follows that in equipping a large factory with slow-speed motors the cost is necessarily great. The interest on this extra cost (over the cost of a system of belting) often offsets the gain in efficiency — at least in part.

In equipping a plant with slow-speed direct-connected motors one must take into account the great economy in fuel, the better conditions of running and controlling the machinery, and the much increased working efficiency of the employees. These are the results that follow the electric equipment of a factory. When the first cost of electric apparatus is not absolutely prohibitive it is advisable to adopt the electric system of direct driving or else electric driving by means of short lines of shafting.

In many cases, however, the first cost of electric equipment makes it out of the question. In such cases for instance as where fuel is very cheap, efficiency in running is not so important as economy in the first cost of the plant.

The student should make a very careful study of the various representative types of slow-speed motors shown in this book, noting the various applications illustrated. He should also find out for himself the selling prices of such apparatus, and he may then decide whether the expense of the electric system is justified

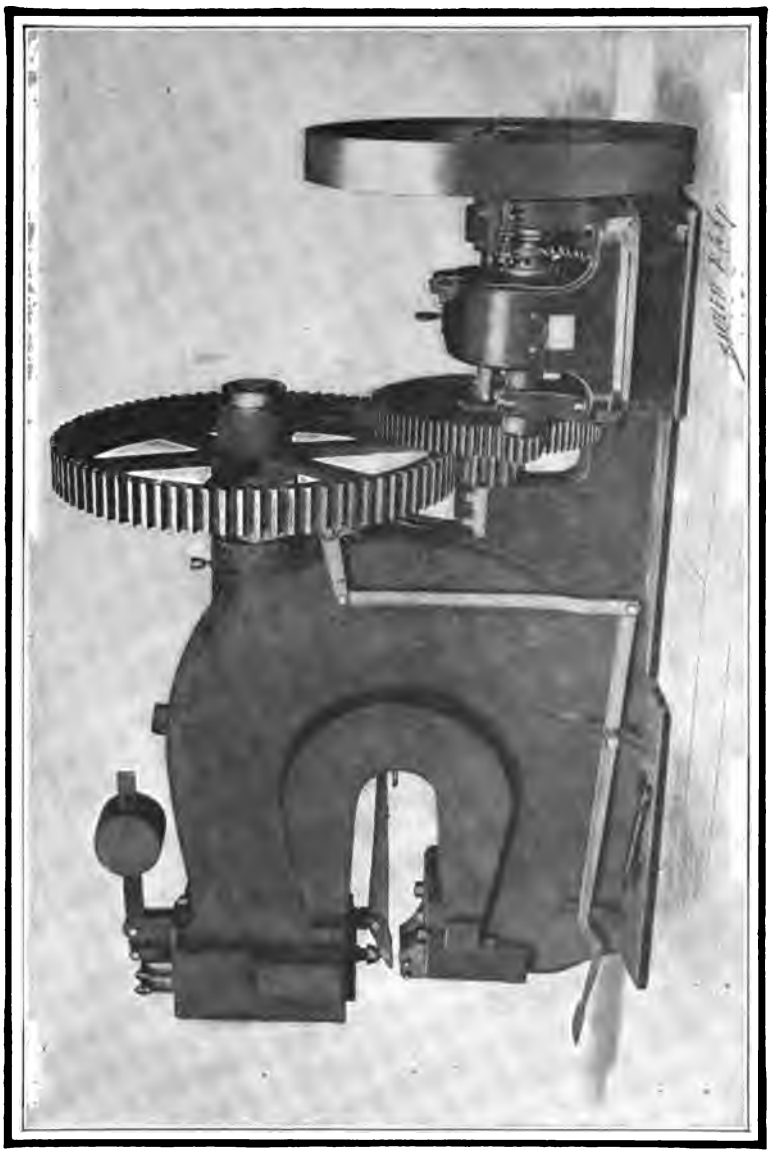


Fig. 70. Westinghouse Motor Operating Punch.

in any special case. The tendency of the times is unmistakably in favor of electric driving. The newer types of motor are as substantially built, as little likely to break down, and as easily regulated as first-class steam engines. The old, unventilated and high-speed motors on the other hand were generally delicate, subject to breakdowns, often wasteful of power, noisy, and not perfectly steady in operation.

A typical high grade modern motor for direct driving is

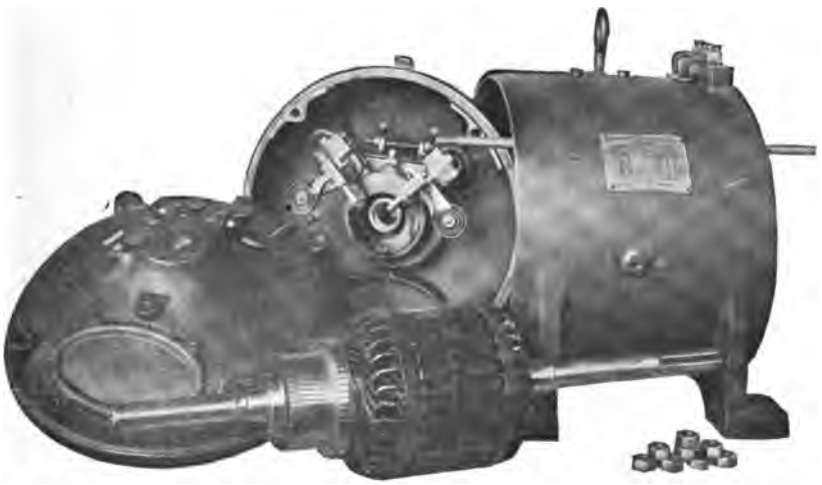


Fig. 71. Westinghouse Dust-Proof Motor.

shown in Fig. 67. This is made by the **Crocker-Wheeler Company** and follows in a general way the design of typical slow-speed direct connected generators. The motor has no shaft of its own, as it is intended to be keyed directly onto the shaft of the machine which it is to drive. It is built for various voltages and speeds, runs smoothly, and is well adapted to a variety of mill and factory applications.

The electric motor is now required for service in very diffi-

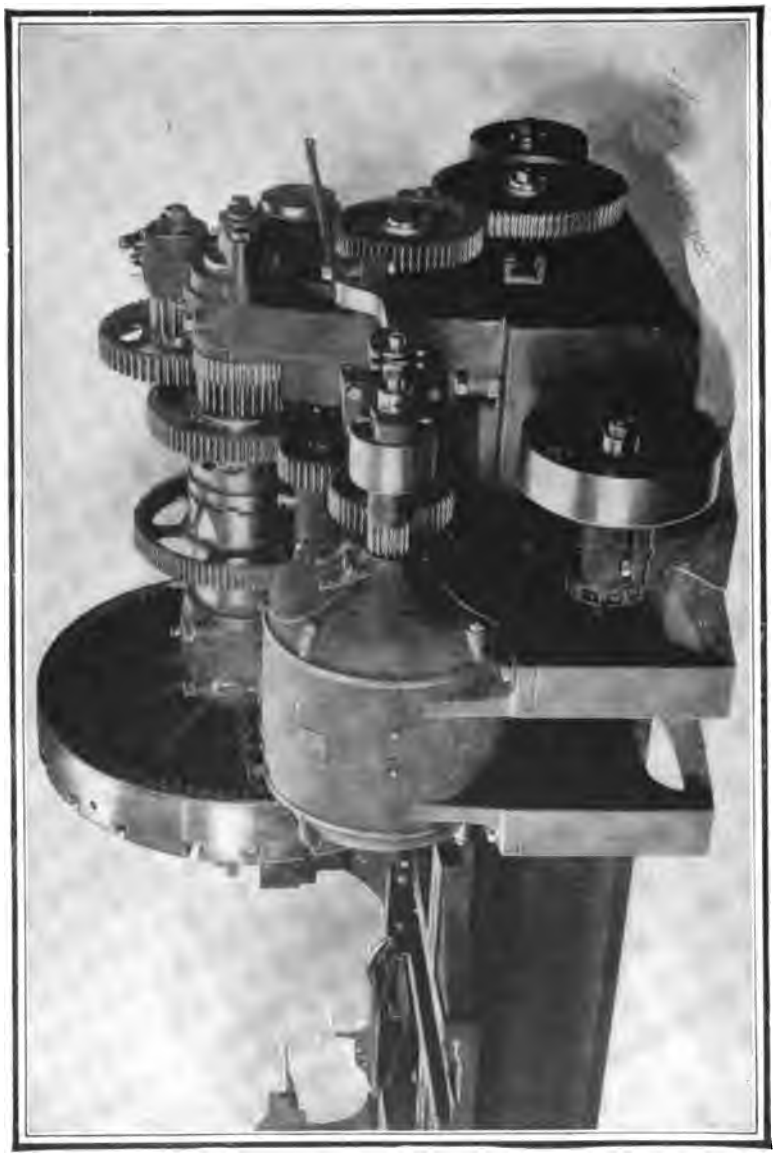


Fig. 72. Westinghouse Dust-Proof Motor Operating Gun Lathe.

cult situations in which the earlier type of motor would speedily have been ruined. Thus in steel mills, flour mills, woodworking shops, boiler rooms, etc., etc., where the air is continually filled with fine particles, the motor must be of unusually substantial construction.

The motors for such service are often enclosed in a practically air-tight case of steel. Such motors, of course, are larger for a given output than open, ventilated motors, as a motor which is enclosed cannot be so well ventilated, and must, therefore, carry larger conductors in order to compensate for heat losses. But large conductors even when heated up might give a better efficiency than could be shown by a well-ventilated motor wound with too small wire.

Fig. 68 shows a Crocker-Wheeler dust-proof motor. In this motor the "iron-clad" armature is completely encased in a cast-steel box, forming the frame of the field. While such motors are not very well adapted for continuous running, they serve admirably for use in intermittent service. The interior of the machine may be reached through the air-tight lid seen in the left-hand figure.

The Crocker-Wheeler Company makes a variety of mill motors designed for connecting direct to the shaft of the machinery which they drive. At slow speeds they are designed to give a very heavy torque, being compound wound with a small shunt.

Slow-speed motors for a given weight of material have usually a smaller output of power than the high-speed types. This in no way means decreased electrical efficiency, but simply that the slow-speed motor (for a given horse-power rating) is heavier and larger than the high-speed type. On the other hand, the slow-speed type runs cool and has far better mechanical construction. Its efficiency is ordinarily very high, and it is much better adapted for long-continued heavy loads than the high-speed motor.

Fig. 69 shows a **Westinghouse** multipolar direct current motor operating a pair of shears for cutting heavy steel plates. Fig. 70 shows a Westinghouse multipolar direct current motor operating a punch with a 36-inch throat.

Fig. 71 shows the Westinghouse dust-proof motor taken

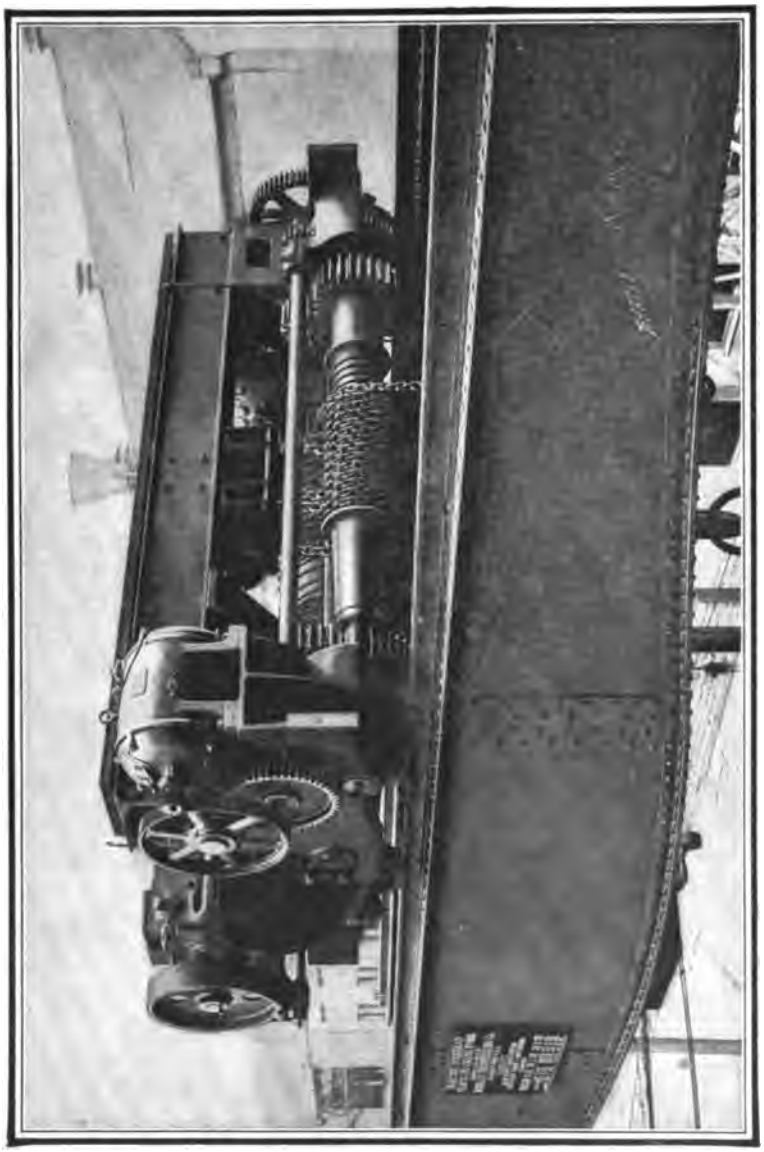


Fig. 73. Westinghouse Motors Operating Out-Door Crane.

apart. The armature, commutator and shaft are shown together; the brushes and brush-holder are seen attached to the interior of one of the lids of the motor case; the field poles are hidden by the frame of the motor. Fig. 72 shows the dust-proof motor operating a 50-inch gun lathe. Fig. 73 shows dust-proof motors mounted upon and operating an outdoor crane at Pittsburg, Pa.

Fig. 74 shows a multipolar motor manufactured by the **Bullock Electric Mfg. Co.**, and designed for driving mill and fac-

Fig. 74. Bullock Multipolar Motor.

tory machinery without belting. These motors are usually geared to the shaft of the machine tool which they operate.

The Bullock motor for work of this character is, as seen in Fig. 74, of a compact, strong design. It is made either of the dust-proof type shown in the figure or of the open, ventilated type. The enclosed or dust-proof type is useful in all cases where the motor is exposed to iron filings or quantities of dust, but being less completely ventilated than the open type a somewhat larger size for a given grade of work may be required. The enclosed motor works admirably however when the load is intermittent, as the motor has ample opportunity to cool in the intervals of work. Figs. 75, 76, 77 and 78, show applications of Bullock motors to machine tools of various kinds.

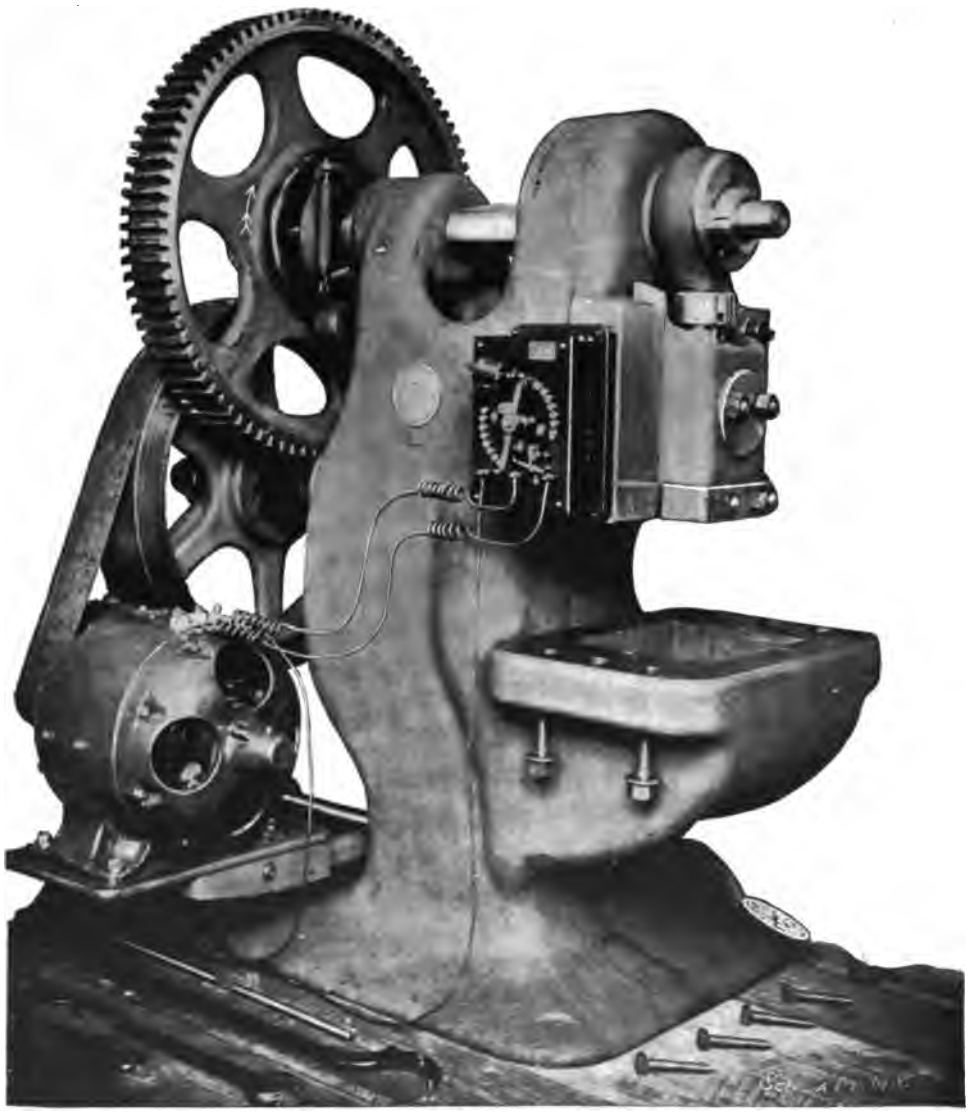
Fig. 79 shows a Bullock direct current motor installed underneath a large Hoe sextuple press with color attachment. The motor is direct connected to the press, and its speed is controlled by the movement of the hand-wheel. The motor may be started slowly and then run through a succession of increasing speeds up to full speed. Fig. 80 shows a Bullock motor connected to a Cottrell perfecting magazine press, and Fig. 81 shows these motors connected to a number of magazine presses in the pressroom of *Munsey's Magazine*.

Fig. 82 shows the **Lundell** 6-pole single field coil medium-speed motor manufactured by the Sprague Electric Co. It is

Fig. 75. Bullock Motor Application.

made in sizes of from 10 to 60 H. P. and runs at speeds of from 600 to 950 R. P. M. The field frame is cast in two pieces, the pole pieces being cast together with the yoke. The bearings are self-aligning and self-oiling, and are supported by brackets secured to the pole frame of the motor. These motors are semi-enclosed, the commutator being exposed and accessible for inspection.

A feature of these machines is the division of the field frame into two symmetrically placed halves bolted together in a vertical plane. The bearing pedestals are removable, and the two halves of the field frame may be moved out *sideways* for dismembering the machine. These motors are ordinarily wound for 115, 230 and 500 volts, but are also wound for any special voltage.



ELECTRICALLY OPERATED GEARED PUNCHING PRESS

Fig. 83 shows the Lundell round-type motor with self-aligning and self-oiling bearings, with side doors fitted to the openings in the frame on the commutator end, making the motor wholly enclosed if so desired. Motors of the same class are also made for slow speed, specially adapted for driving printing-presses and similar machinery.

High and low speed direct current motors are manufactured by the **Triumph Company** as follows: Fig. 84 shows the Triumph slow-speed direct-connected motor, and Fig. 85 shows

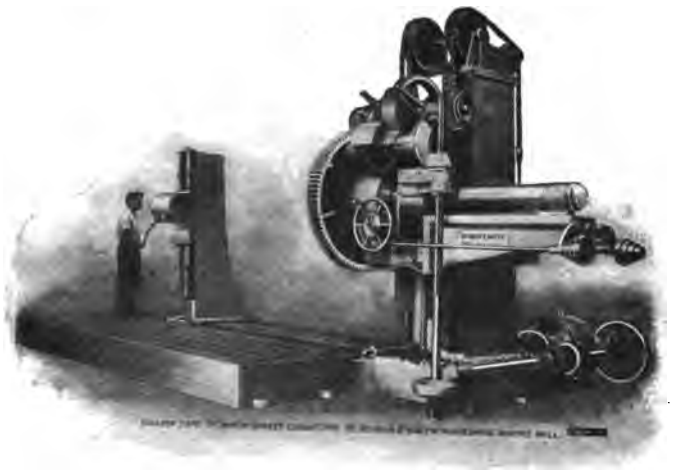


Fig. 78. Bullock Motor Operating Boring Mill.

several important applications of the Triumph motor. A small Triumph motor, intended for use in places where the motor is exposed to dust and dirt, is seen in Fig. 86. It is encased in a cast-iron frame, but the commutator may be reached by removing the doors. These doors, if desired, are perforated with numbers of holes provided for ventilation, a fine screening being fastened inside the door to prevent the ingress of dirt. This motor may be bolted to floor, wall or ceiling.

Triumph machines are characterized by field frames of soft cast iron and laminated pole pieces built up of sheet iron and cast welded into the frame. The pole pieces are fitted with cast-iron

"shoes," the horns being shaped to give a suitable magnetic field. Field frames are divided vertically in some instances and horizontally in others. The field coils are separately wound on forms and slipped into position upon the pole pieces. The armatures

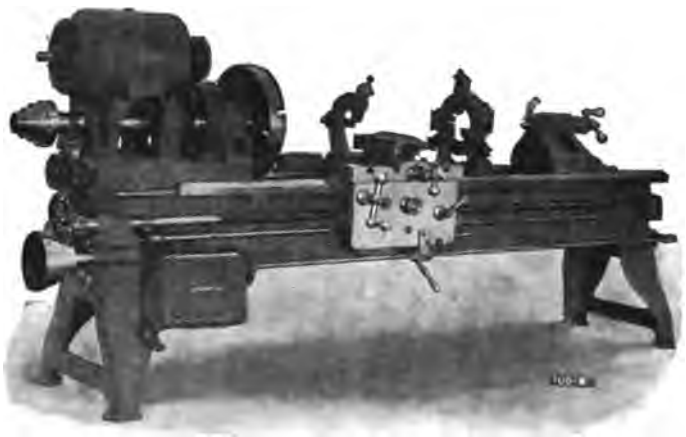


Fig. 77. Bullock Motor Operating Lathe.

are iron-clad with laminated cores and are of the toothed type. The slots are insulated by troughs of fullerboard, mica and paper. Coils are held in position by wooden wedges without binding

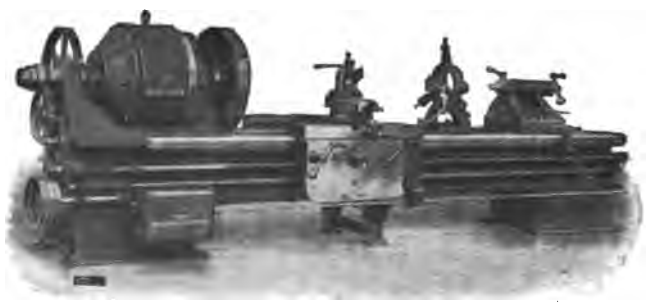


Fig. 78. Bullock Motor Operating Lathe.

wires. The lower half of the field frame and the pedestals are made in one casting, an arrangement which gives accurate centering. Armatures are bar wound and so constructed as to allow free circulation of air.

Fig. 87 shows the **Western** enclosed motor suspended from the ceiling and arranged for transmission of power by belt and pulley. The bearings which support the countershaft are secured to the motor by brackets bolted to the frame of the motor. By shifting the position of these brackets the countershaft may be swung completely around, so as to hang directly beneath the motor or at the extreme right-hand side. The large gear-wheel will, of course, remain in mesh with the pinion carried by the

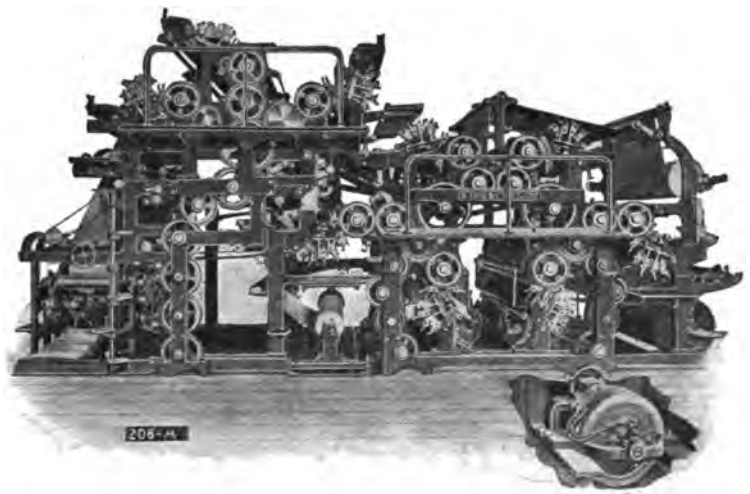


Fig. 79. Bullock Motor Operating Printing Press.

armature, whatever position the countershaft may occupy. This appears to be a very valuable arrangement, giving the motor unusually extended range of adjustment.

Fig. 88 shows the **Fort Wayne** 4-pole belted motor. The frame and right-hand bearing are cast in one piece, of the best quality of iron. The pedestal upon the pulley end of the shaft may be unbolted and the armature may then be slipped off for repairs. The construction shown gives very great rigidity. These motors run from 300 to 600 R. P. M.

Fig. 89 shows the **Commercial Electric Company's** "iron-clad" moderate-speed motor. These machines are designed to give the best possible protection to the motor windings when the machine is exposed to the weather or to a dust-loaded atmosphere.

The casing has large doors or panels which may be opened for inspecting the interior.

Commercial motors are also made to hang from the ceiling. (See Fig. 90.) This motor runs on slide rods, by means of which the belt may be adjusted.

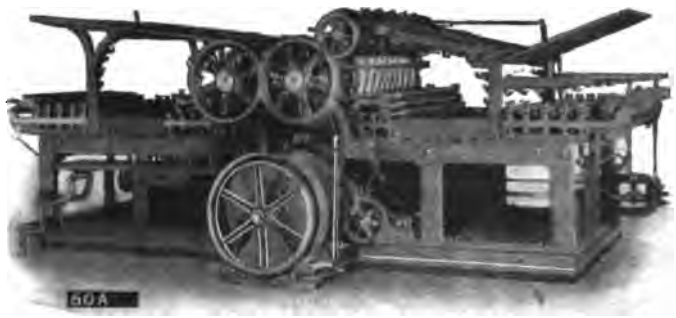


Fig. 80. Bullock Motor Operating Printing Press.

Fig. 91 shows a large-size Commercial multipolar motor for belt driving.

C & C motors are shown as follows. The special C & C motor which may be wound for a variety of speeds and capacities

Fig. 81. Bullock Motors in a Magazine Press Room.

is seen in Fig. 92. If the motor is desired for exceptionally slow speed, it is wound with two commutators and double arma-

ture windings. Fig. 93 shows an interesting type of C & C motor intended to run with its shaft in a vertical position, and Fig. 94 shows an open type of C & C motor intended for horizontal running.

The C & C Co. and the Westinghouse Co. recommend the grouping of machine tools together, a single electric motor being

Fig. 82. Lundell Six-Pole Motor.

used to drive the group through a short shaft. This avoids the expense of individual motors and does away with long lines of shafting. Any machine which runs for a large part of the time at light load cannot be run economically by an individual motor, as the motor would be running during a large part of the time at so light a load as to show poor efficiency. By grouping several

machine tools together and running them by a single motor it is possible to obtain a much more uniform load for the motor, as the chances are that one tool might be running light while another was heavily loaded, and so on.

**The Northern Electrical Manufacturing Company** manufactures an excellent line of motors for direct and indirect driving. Types of these motors are illustrated in Figs. 95, 96 and 97. The motors shown in Figs. 96 and 97 are of the enclosed type, but in Fig. 96 may be seen a ventilated shield or cover for the commutator and brushes through which a supply of air circulates. Motors designed for direct connection, as we have said, are highly desirable in the larger sizes, because of their superior efficiency. In the very small sizes, the direct connected type is also extremely convenient because of its compactness and the absence of noisy gear-wheels.

Fig. 95 shows a particularly attractive design for direct connection.

Fig. 83. Lundell Motor with Covers.

## RAILWAY MOTORS.

The modern trolley car is usually of very heavy construction, carries heavy loads and must make long continuous runs at high speed. The motors occupy a cramped position under the body of the car, are exposed to the hardest conditions from dirt and water,

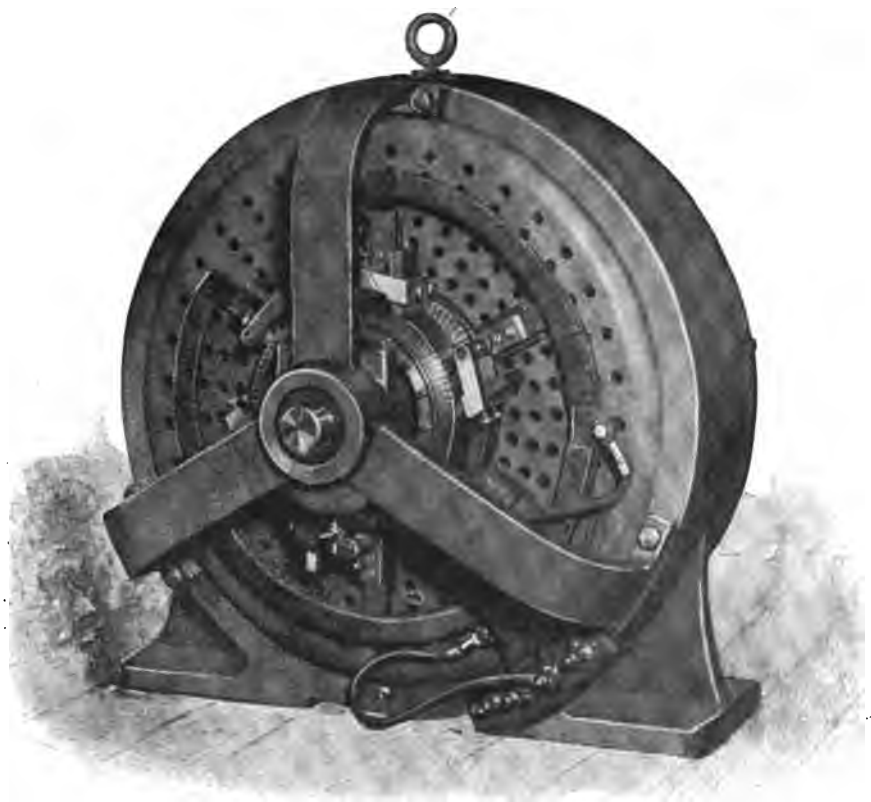


Fig. 84. Triumph Motor.

and ventilation is greatly interfered with by the requirements of compact design. Yet the motor must run fairly cool at ordinary loads and must stand very heavy overloads for a short time.

Modern railway motors meet these difficult conditions admirably; a complete breakdown of the insulation is very rare and mechanical injury is well guarded against. Whereas a few years

ago a 25 H. P. car motor was considered large, the recent designs run up to 150 H. P. In fact there are now in use electric car motors running up to 250 H. P., four of these being used upon a single large car on one of the European electrical roads.

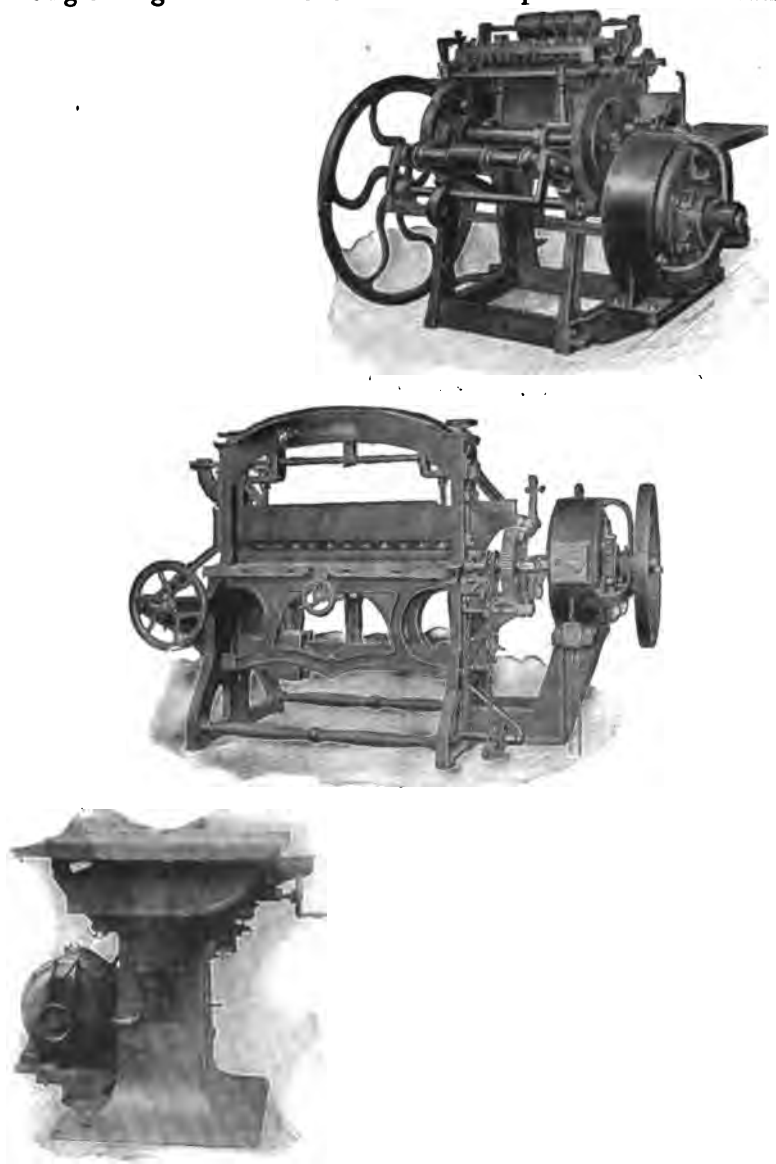


Fig. 85. Triumph Motor: Miscellaneous Applications

These motors are, however, of the "induction" type, and are discussed in "Alternating Current Machinery." We believe that 150 H. P. is about the maximum size of direct current car motor thus far introduced into regular service.

Fig. 98 shows a **General Electric** (GE-73) railway motor. The axle runs through bearings bolted to the main casing of the motor; the gears are enclosed as shown at the right-hand end of the cut; the motor frame is a single casting, carrying four poles attached to its inner face by bolts. This construction is widely approved of, as it gives a compact, strong motor. In order to remove the armature it is necessary to unbolt the armature bear-

Fig. 86. Small Triumph Motor.

ings, after which the armature may be slid out endwise. This is a difficult matter and necessitates removing the motor from the truck. Repairs, however, are rarely necessary with a motor of such strong construction.

Fig. 99 gives a rear view of the same motor. The various leads are seen introduced into the casing, all connections being made inside. Access to the interior is obtained by means of the various lids and handholes which the motor carries. The pinion seen in this illustration is carried upon the armature shaft, the gear-wheel with which it engages being carried upon the car axle.

Such a motor is practically dust and moisture proof. When running under suitable conditions the lids are left open for ventilation, although the motor is designed to run without excessive heating in ordinary use. The motor shown has a rating of 75 H. P., based upon a rise of 75° C. during one hour's run at full load.

Fig. 100 shows the **Westinghouse** No. 56 railway motor which runs up to 100 H. P. It runs on interurban lines where

Fig. 87. Western Enclosed Motor Suspended from Ceiling.

it must operate continuously for long periods. The motor is enclosed in a steel casing, but although ventilation is restricted the motor runs comparatively cool. Fig. 101 shows the motor opened up by means of hinges cast into the casing, the main casing being in two sections. In this illustration the pole pieces are seen surrounded by the field coils, and an excellent view of the armature windings, commutator, bearings and pinion is obtained.

Motors of this design are almost perfectly dust and moisture proof, but will not endure complete submergence in water.

In railway motors there must be as stated before a considerable overload capacity, to meet the requirements of starting under heavy load, and for climbing grades, etc. It is first-class practice, if a motor has a continuous capacity of 50 amperes, to provide for a current of 100 amperes for 15 minutes, or a load

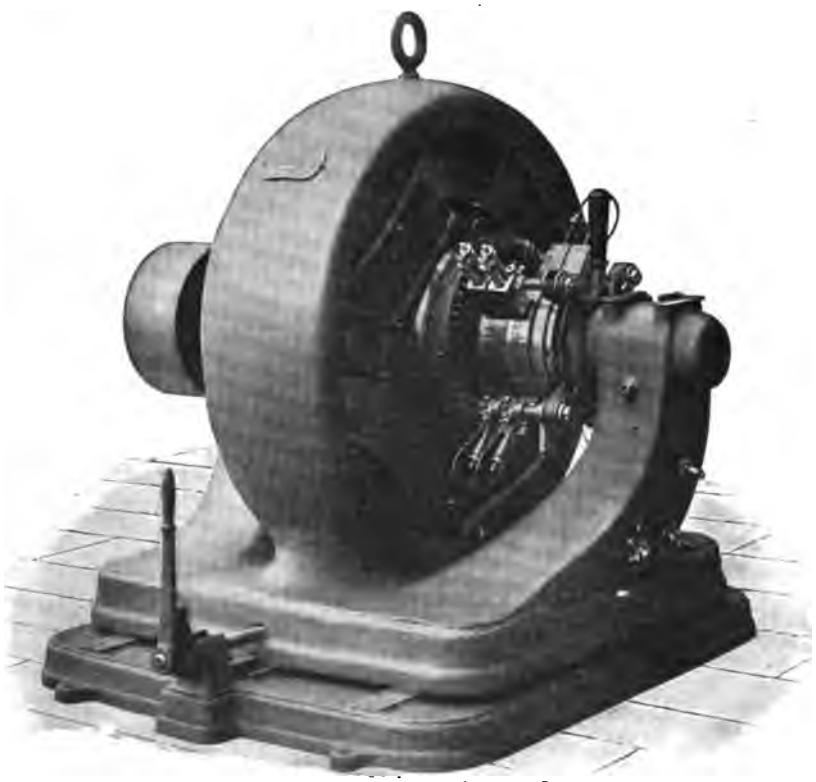


Fig. 88. Fort Wayne 4-pole Belted Motor.

of 140 amperes for 5 minutes, or 60 amperes for one hour and twenty-five minutes. This is the specification of the Westinghouse No. 56 motor, based upon a maximum temperature rise of 75° C.

Fig. 102 shows a Westinghouse No. 49 motor which is designed for medium-speed city and suburban service. It carries

four laminated pole pieces cast welded into the yoke or casing. The two halves of this casing are hinged together and may be opened up for inspecting the interior or removing the armature. Such motors may be repaired in position upon the car. The armature is slotted, carries ventilating ducts and is wound with light binding wires.

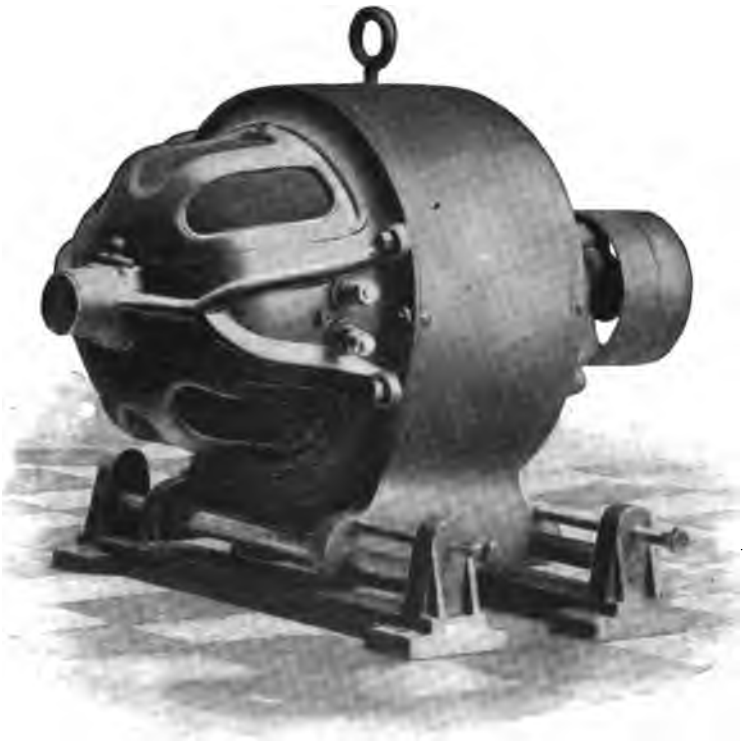


Fig. 89. Commercial Electric Co.'s "Iron-Clad" Moderate-Speed Motor.

## ELECTRIC LOCOMOTIVES.

Electric power is now applied extensively to mining operations, for hauling the ore cars, operating the pumps, and in fact running all the machinery of the plant for mining and milling ores. The development of mining properties in which low grades of ore are handled has made it necessary to economize in the running expenses of the plant in all possible ways, and in substitut-

ing electric power for mules in hauling cars a very surprising saving is effected.

Fig. 103 shows the **General Electric** mine locomotive operated from an overhead trolley, and Fig. 104 shows end views of similar locomotives.

In most mine passages there is very little head-room and it will be seen in the figure that the locomotive is of unusually low design. In fact, the maximum height of such a locomotive (not including the trolley pole) is in many cases not more than 36 inches, and rarely exceeds 50 inches.

The locomotive is controlled from the operating platform at

Fig. 90. Commercial Electric Co.'s Motor Suspended from Ceiling.

one end, where the operator sits. The equipment of the locomotive is similar to that of a trolley car. In addition to the motors there are the usual controller, rheostat, etc.

Mine locomotives are generally designed to run at speeds of from 6 to 8 miles per hour. As the track gage is in most mines extremely narrow (usually about three feet), and as the locomotive is of very limited height, it is evident that there can be but little room for the motors and their suspension gear. By skilful designing, however, it has been found possible to construct mine

locomotives in which the essential features of first-class street railway power equipment are preserved. Such locomotives run cool, are easily controlled, and highly efficient in operation.

Fig. 105 shows the **Bullock** electric locomotive and crane car for use on surface lines. It is equipped as a locomotive, capable

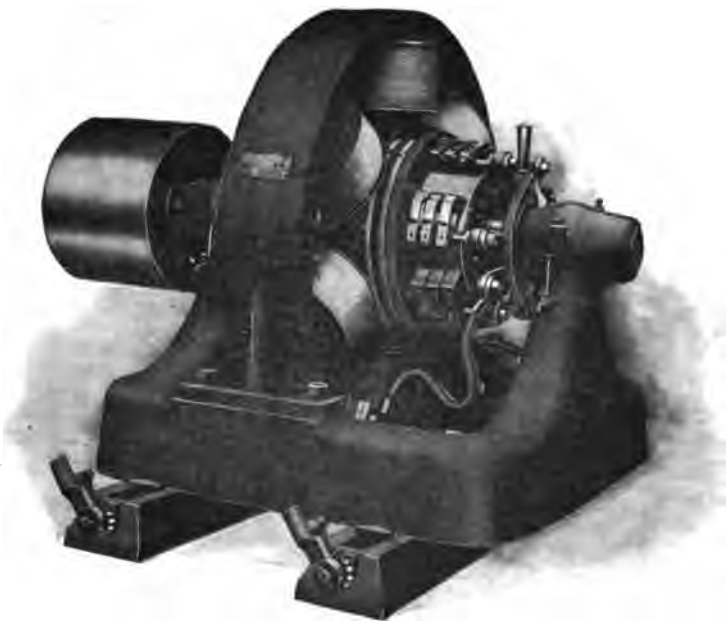


Fig. 91. Commercial Multipolar Motor for Belt Driving. (Large Size.)

of handling eight loaded freight cars on a level track. It is propelled by two motors, one on each axle, wound for any desired voltage. The illustration shows two trolley poles, with trolleys running on two wires, thus avoiding the necessity of grounding the circuit. This practice is common where the electric locomotive is used in connection with factories, the circuits of which it would be undesirable to ground.

The locomotive is of heavy construction, the extra weight being useful as a counterbalance for the crane. The wheel base is 9 feet long, and 33-inch railroad car wheels are used.

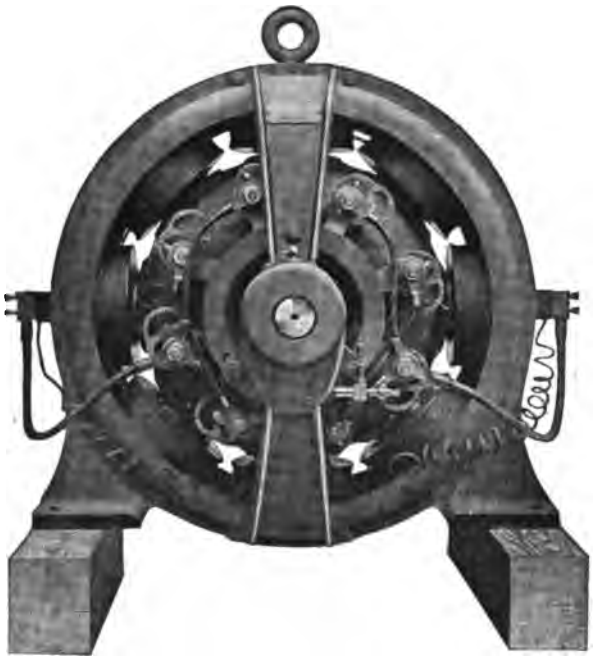


Fig. 92. C & C Special Motor.

Fig. 93. C & C Motor run with Shaft in Vertical Position.

Fig. 94. Open Type C & C Motor for Horizontal Running.

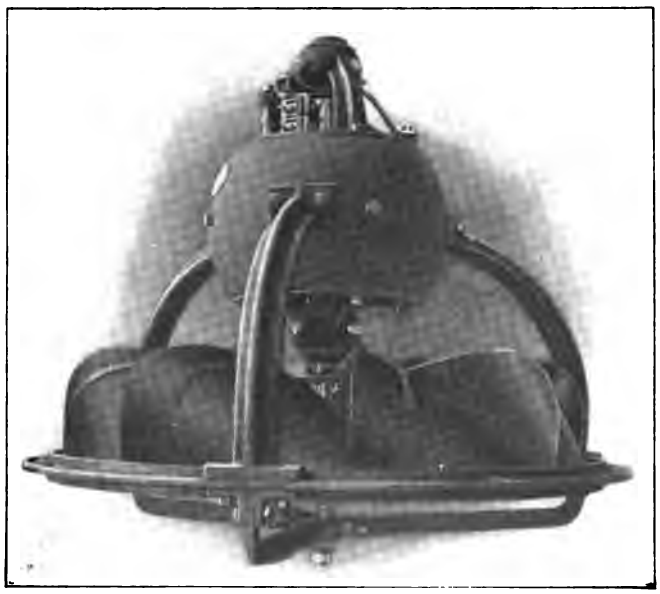


Fig. 95. Northern Motor Driving Ventilating Fan.

Fig. 96. Northern Enclosed Motor with Vertical Shaft.

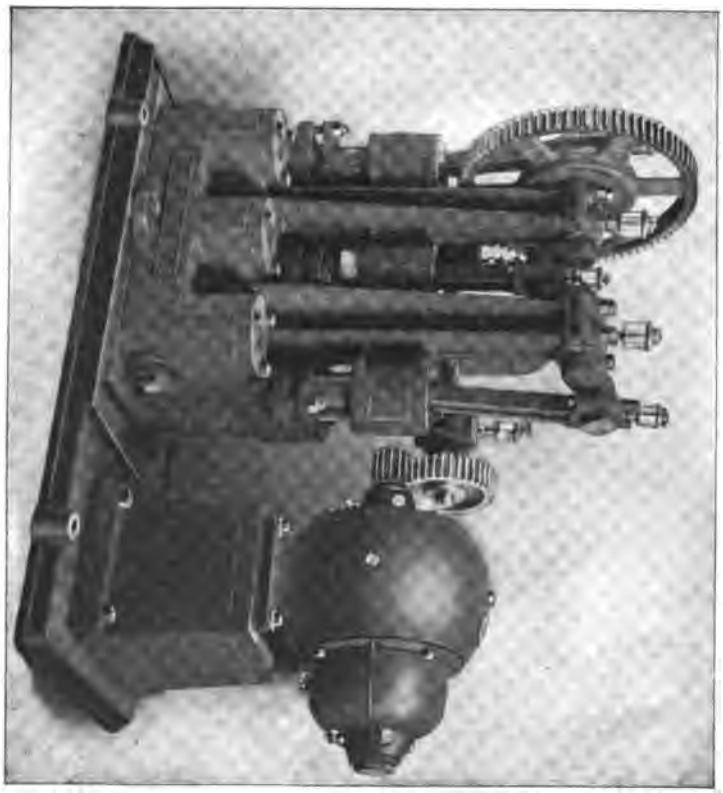


Fig. 97. Northern Motor Operating Triplex Pump.

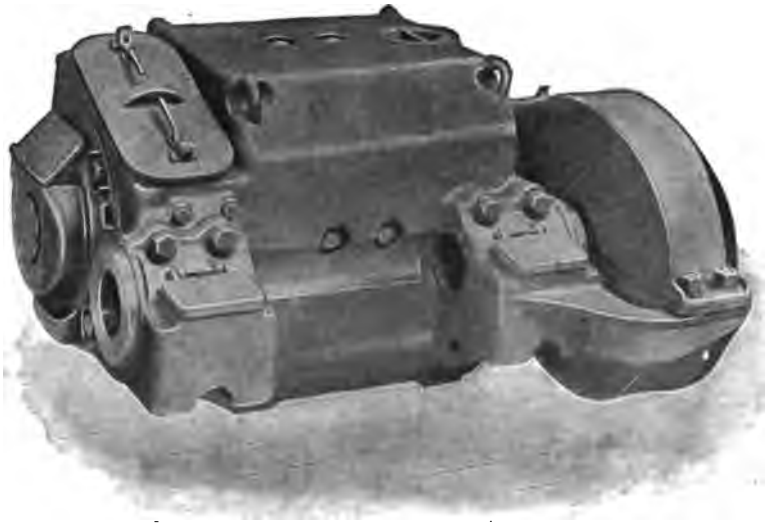


Fig. 98. General Electric Railway Motor.

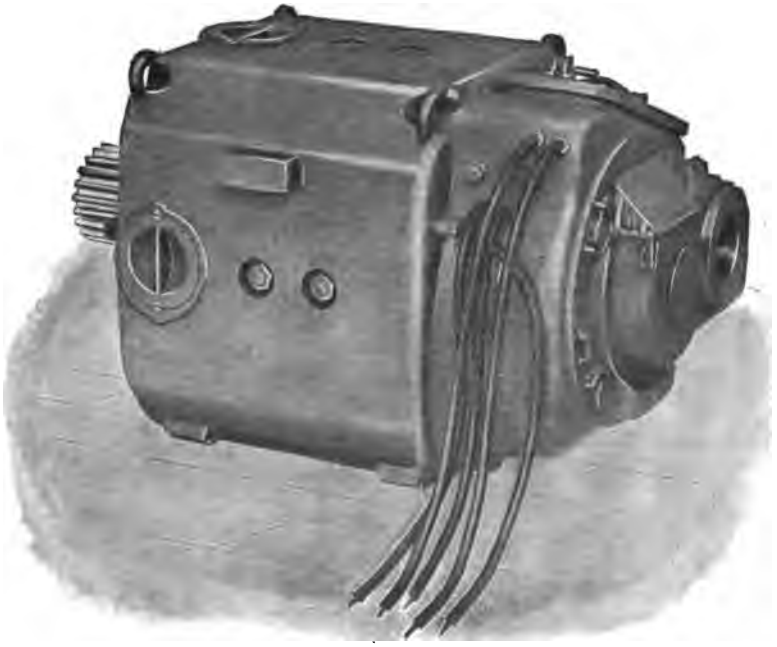


Fig. 99. General Electric Railway Motor, Rear View.

Fig. 100. Westinghouse Railway Motor.

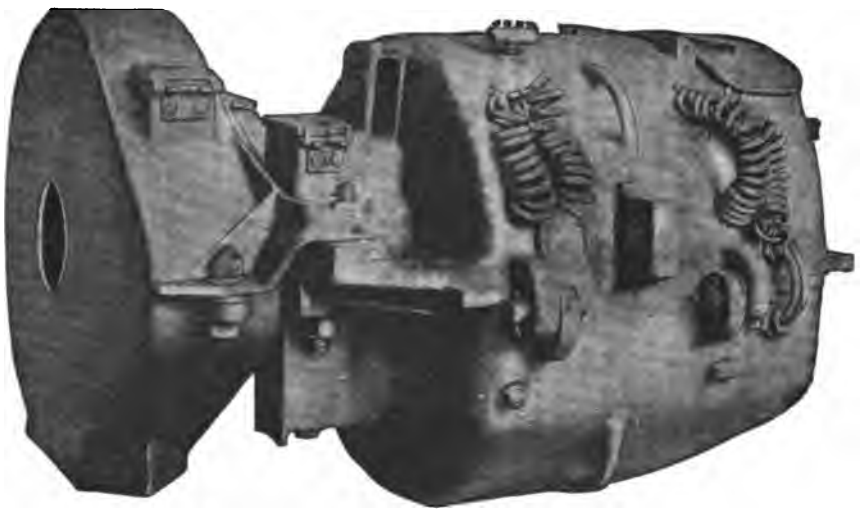


Fig. 102. Westinghouse Medium-Speed Railway Motor.

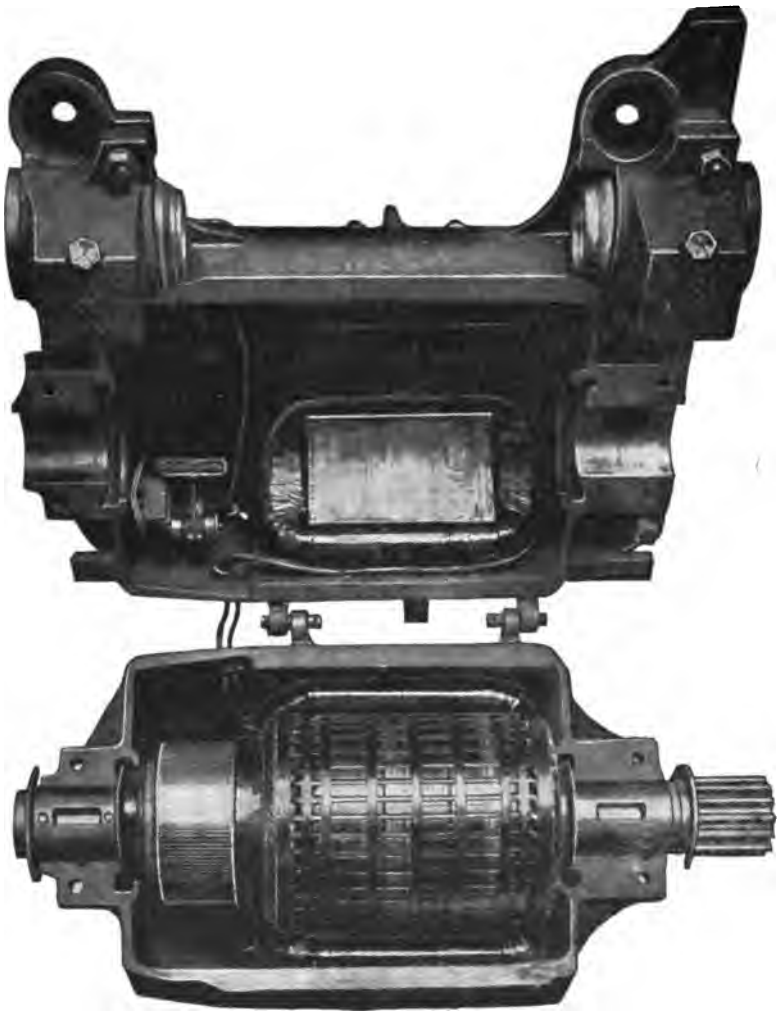


Fig. 101. Westinghouse Railway Motor, Open

Fig. 103. General Electric Mine Locomotive.

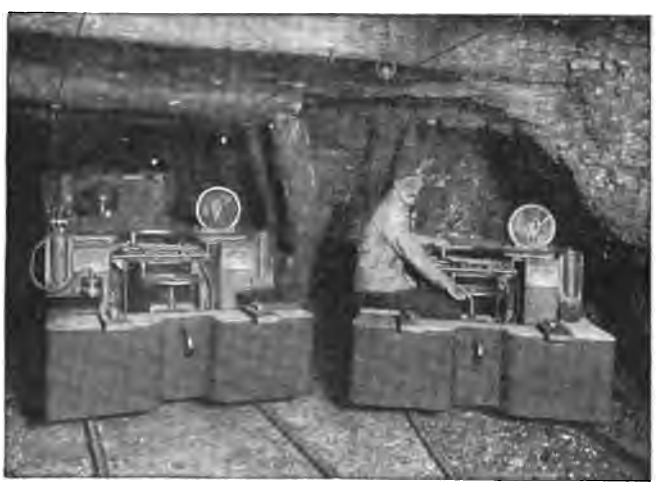


Fig. 104. General Electric Mine Locomotives.

Fig. 105. Bullock Electric Locomotive and Crane Car.

The above are modern American types of generators and motors for miscellaneous direct current work. The reader should bear in mind that the types here shown are representative, and are intended merely to give a general idea of contemporary practice. There are very few classes of mechanical work in which special motors are not now constructed. The number of these is accordingly very large, and it would be impossible in a book of this character to describe all of the special designs of motor and generator which are now on the market. Two most important classes of work are elevator and automobile service.

The automobile motor is in effect a miniature railway motor, of the enclosed type, and operated from a battery of 40 or 44 storage cells. It ranges in size up to 6 H. P., as made by the foremost manufacturers, and the larger automobiles frequently carry two such motors, one for each of the two rear wheels. Occasionally motors are used upon the front wheels.

Motors of this class are as yet too new to show standard practice, although a number of satisfactory makes are now in practical use. The next few years will probably show great advance in this line of work.

The electric elevator motor is now in very extensive use, both for operating elevators through rope driving gear and also

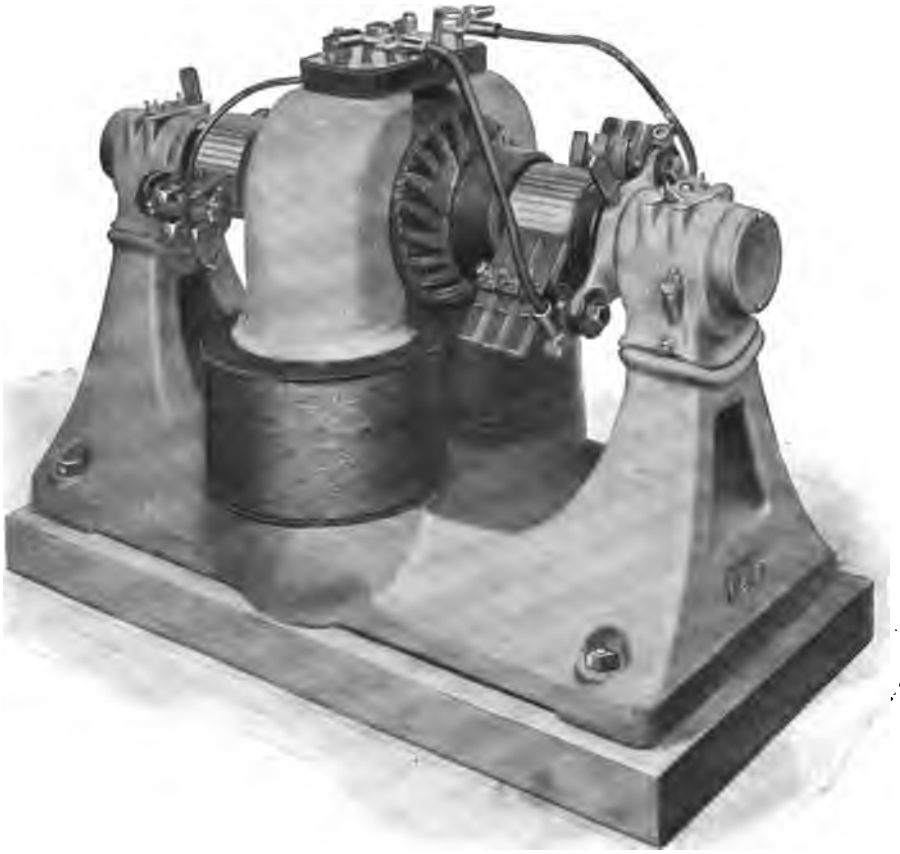


Fig. 106. Western Electric Co.'s Dynamotor.

for pumping water for hydraulic elevator machinery. Elevator motors are of the most substantial construction and are equipped with controllers having a large range of speed adjustment. Crocker-Wheeler elevator motors are supplied with an automatic band brake, which appears to be a highly valuable

feature. Elevator motors must, of course, be self-starting under heavy loads, and must be reversible.

As it is impossible to treat of all these classes of motors in a brief discussion, we have confined our attention mainly to the larger sizes and the more important applications of electric apparatus. In fact, it is only in the larger sizes that modern practice has developed standard types such as are here shown. The smaller machines, whether for general or special applications, are made in almost limitless varieties of shape and size.

## MOTOR-GENERATORS AND DYNAMOTORS.

In many electric plants for power and lighting an electric motor is seen driving a generator either belted or direct connected to it. In such cases the motor takes the place of a steam engine, the operation of the generator being very much like that of similar machines driven in the usual manner. The purpose of this arrangement is usually to obtain from the generator so driven an output of electricity of different voltage from the main supply of the station. Thus a station supplying a trolley line at 500 volts may require a small supply of electricity for house-lighting at 110 volts. In instances like this a motor operating from the 500-volt circuit might be employed to drive a generator designed for supplying current at 110 volts. Such a combination of motor and generator is clumsy, and it is now customary to use for this service a combination machine known as a motor-generator, consisting of a motor and a generator running on the same shaft and having a common bedplate. A further modification of this design is known as the dynamotor. In the dynamotor there is but one armature and one field magnet. The armature is wound for the voltage supplied by the station, in the case cited above 500 volts, and together with the field magnet constitutes a motor operating like any simple direct current motor. The commutator for this motor winding is built upon one end of the armature shaft in the usual manner. The armature furthermore carries a separate set of windings, the terminals of which are brought out to a commutator upon the end of the shaft opposite to that carrying the motor-commutator. This second set of windings, acting under the influence of the field magnet and revolving with the motor

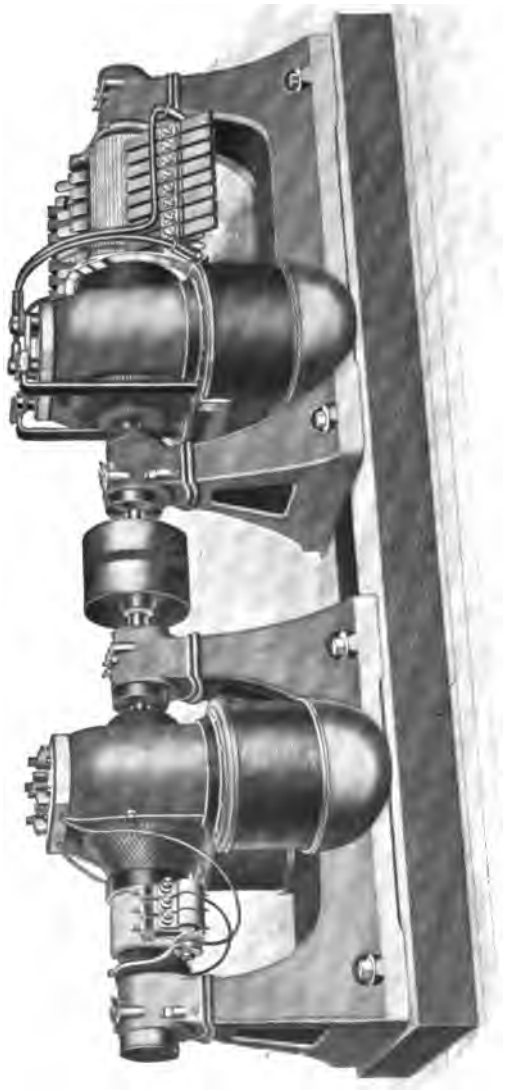


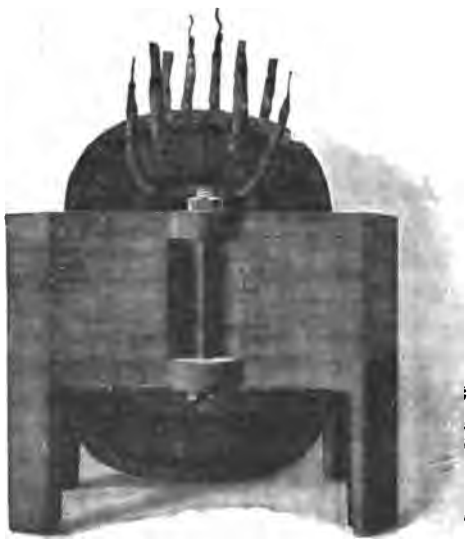
Fig. 107. Western Electric Co.'s Twin Motor-Generator.

windings, gives out a current of (in the case cited) 110 volts.

The dynamotor manufactured by the **Western Electric Co.** is shown in Fig. 106. A machine of this class is cheaper, more compact and of less weight than the motor-generator, and is also slightly more efficient. The dynamotor, however, has this disadvantage, that the secondary voltage — that is, the voltage on the generator side of the machine — cannot be varied to any extent except by introducing into one or the other of the circuits a certain amount of dead resistance. Also the generator side of the dynamotor will not have a constantly maintained voltage, owing to the resistance of the armature, and the machine cannot be wound to compensate for this change of E. M. F. On the other hand, the dynamotor will carry heavier overloads than the motor-generator.

Fig. 107 shows the Western Electric Co.'s motor-generator, or as this company styles it, the "Twin Motor-Generator." This machine has an advantage over the dynamotor inasmuch as it can be compounded to maintain a voltage on the generator side that will be constant, or, if required, to give a generator voltage that will rise in proportion to the load. In the twin motor-generator, moreover, the motor and generator circuits are insulated much more effectively than in the case of the dynamotor, in which the insulation depends upon wrappings between the two armature windings carried upon the same core. It is evident that there is very little essential difference between the dynamotor and the motor-generator. Some manufacturers show a preference for one design, and some for the other.

**Boosters.** A machine of the general class of dynamotors and motor-generators is the booster. It is in effect a motor driven usually from an electric light circuit and driving a separate generator mounted upon the same shaft. The voltage of such an electric light line usually falls off considerably at points distant from the station, and the purpose of the booster is to raise the voltage of the line up to standard at points where it shows such a falling off. Accordingly the generator portion of the machine is connected with the electric light circuit in such a way that its voltage (which is sufficient to compensate for the amount lost by the line) is added to the E. M. F. of the circuit



**Type "M" Wagner Transformers, 3 to 50 K. W. Sizes.**

## SECTION 2.

# ALTERNATING CURRENT MACHINERY.

### PRINCIPLES OF ALTERNATING CURRENTS.

The alternating current is produced under the influence of a rapidly alternating E. M. F. Such a current rises and falls in strength as well as changes its direction. These changes occur very many times a second, and introduce peculiarities which do not occur with direct currents.

We have seen that when a coil of wire revolves in a uniform field of force, the E. M. F. generated when passing through one-half a revolution, is opposite to that generated during the other half. Also that by means of a commutator the resulting alternating currents are changed to give a direct current in the external circuit. Fig. 1 illustrates the varying E. M. F. generated in a simple coil of wire revolving in a uniform magnetic field. Vertical distances from the central line to the curve represent the

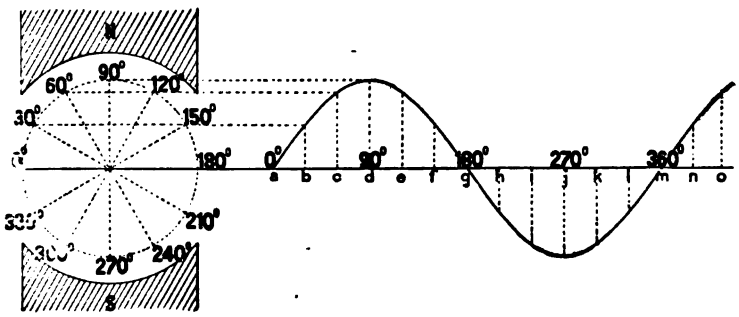



Fig. 1.

values of the E. M. F. when the coil is in different positions. Let us consider a wire perpendicular to the paper to revolve with a uniform motion between the poles *N*, *S*. The E. M. F. generated in the wire depends upon the rate at which it cuts the lines of force of the field. Suppose the wire to start from the left-hand side on the dotted circle. In this position the conductor is moving ***parallel*** with the magnetic field and no E. M. F. is generated. The

ordinate at *a*, which represents this position, is consequently zero. After the wire has moved through 90° it is then moving *across* the lines of force and at right angles to them. The number of lines cut at this point is therefore a maximum and the E. M. F. is represented at *d*. At the intermediate points 30° and 60° between 0° and 90°, the E. M. F. gradually increases as represented at *b* and *c*, the relative values at any time being represented by the distances above the horizontal line. After passing the 90° point, the E. M. F. gradually decreases until at 180° the wire is again moving parallel to the magnetic field. No E. M. F. is then generated as represented at *g*. The wire now begins to cut the magnetic lines in an opposite direction and the E. M. F. is consequently reversed. Hence at 210° and 240° the E. M. F. gradually increases in an opposite direction as shown at *h* and *i*. At 270° the maximum E. M. F. is being generated in the reversed direction as represented at *j*. Upon the completion of the 360° of one revolution, the E. M. F. again becomes zero. If the rotation of the wire is continued, this series of changes is repeated during each revolution.

The divisions of the horizontal base line really represent time, but for convenience are scaled off in degrees as the *form* of the curve will be the same whatever the time required to complete one revolution. Points *a* and *g* are therefore said to be 180° apart, *a* and *d* 90° apart, and *a* and *b* 30° apart. As the E. M. F. at *b* is the E. M. F. generated by the wire after having passed through 30°, the point *b* is said to be 30° behind the point *a*, or 30° ahead of point *c*. Similarly *g* is 180° behind *a*, 90° behind *d*, or 180° ahead of *m*, etc.

**Cycle.** The series of changes represented in Fig. 1 from *a* to *m* is called a complete *cycle*, or *period*, and as we have seen, is made by one revolution of a simple coil in a bipolar field. One *alternation* is generally understood to mean one-half of a cycle, and is the change represented from *a* to *g* or from *g* to *m*.

**Frequency.** The number of cycles occuring per second is known as the *frequency*, and is equal to the number of revolutions per second of a simple coil in a bipolar field. Thus, if the coil made 3,600 revolutions per minute the frequency would be 60 cycles per second or simply 60. Alternators are usually constructed with

multipolar field magnets and hence their frequency is greater than the number of revolutions. A conductor on the armature of a multipolar machine will pass through as many fields in one revolution as there are pairs of poles. The frequency of an alternator is therefore obtained by multiplying the number of revolutions per second by the number of pairs of poles. For example, an alternator having 10 pairs of poles and making 800 revolutions per minute will have a frequency equal to $\frac{800}{60} \times 10 = 133$, approximately.

**Virtual E. M. F. and Current.** As the E. M. F. of an alternator is rapidly rising, falling and reversing, the question arises as to what value should be taken as a measure of the E. M. F. The E. M. F. in one direction is equally as effective as the E. M. F. in the other, and therefore the *value* of the E. M. F. is independent of the direction. Hence the E. M. F. may be regarded as always in one direction and constantly rising and falling. As the E. M. F. has a maximum value for only short periods of time, it is evident that this could not be taken as the nominal value. The alternating E. M. F. as well as the alternating current is therefore measured by comparison with the direct E. M. F. and current; and an alternating E. M. F. or current which produces the same effect as a direct E. M. F. or current, is said to have the same voltage or amperage. For comparison those effects are taken which are independent of the reversal of E. M. F. or current. An alternating E. M. F. which produces the same deflection on an electrostatic voltmeter as a direct E. M. F., and an alternating current producing the same heating effect as a direct current are said to have the same values. These values are known as the *virtual* E. M. F. and current, and are given by the readings of an alternating current voltmeter or ammeter. An alternating E. M. F. of 150 volts is therefore sometimes greater and sometimes less than 150. If the curve is a sine curve, like that shown in Fig. 1, then the virtual value is equal to the maximum value divided by the square root of two, or is about .707 of the maximum value. Hence an alternating E. M. F. having a maximum value of 200 volts has a virtual value of $200 \times .707 = 141.4$ volts; or a current having a maximum value of 50 amperes has a virtual value of $50 \times .707 = 35.35$ amperes. If the virtual value is known,

the maximum may be found by multiplying by the square root of two, which is about 1.41.

The E. M. F. of alternators does not usually have exactly the same wave form as that shown in Fig. 1, and the virtual E. M. F. is not always .707 of the maximum. The nearer the wave form approaches the sine curve, however, the closer will be the multiplying factor to .707. The wave form of most machines so nearly approaches a sine curve that the number .707 may be assumed as approximately correct.

The reason that an alternating current system requires a higher insulation than a direct for the same voltage is thus apparent. The maximum value of the E. M. F. may be as great as twice the virtual value, and it is the maximum value to be guarded against.

**Effect of Self-Induction.** We have seen that when a current flows through a wire, the same is surrounded with whirls of magnetic lines, and that by coiling the wire their effect becomes very great. The effect is also considerably increased by supplying the coil with a soft iron core as in the electromagnet. We have also learned that the self-induction of such a coil is very large. When the current increases or decreases, the varying strength of the magnetic field causes an opposing E. M. F. to be set up. With the alternating current this self-induction tends to choke the current down when it is increasing and prevents it from attaining its full strength. The greater the amount of self-induction in the circuit the more is the strength of the current reduced. Hence the effect of self-induction on an alternating current circuit is to *increase the apparent resistance.* A greater E. M. F. is required at the terminals of a circuit containing inductance in order to produce a given current, than is the case with a non-inductive circuit. This *additional* resistance of the circuit due to self-induction is called *reactance* to distinguish it from the ohmic resistance of the conductor. The combined effect of the reactance and ohmic resistance is called *impedance.* The value of an alternating current is therefore obtained by dividing the applied E. M. F. by the impedance of the circuit.

**Choking Coils.** It is evident that if the conductor resistance of a circuit is small and the reactance large, the current

strength will depend almost entirely on the reactance. Advantage is taken of this fact by the use of what are known as choking coils, reactance coils, or impedance coils. These are coils of large inductance and small resistance, and so arranged that the inductance may be varied.

The principle will be understood from Fig. 2. The alternating current is passed through the coil *A*, consisting of large sized wire and having low conductor resistance. The laminated core *C* of soft iron may be inserted or drawn from the coil. When the core is entirely within the coil, the self-induction is large, as the variation and strength of the magnetic field is great. The reactance is then a maximum and the current small. As the core is gradually withdrawn, the reactance becomes less and less and the current increases. With the core withdrawn the reactance is a minimum and the current a maximum.

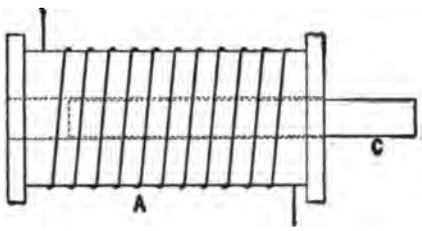


Fig. 2.

Fig. 3 illustrates another form of choking coil. The coil *A* is provided with a soft iron core. A copper cylinder *S* is outside the coil and is movable. When *S* is removed from the coil the reactance is a maximum. When *S* is over the coil, the constant change in strength of the magnetic field induces eddy currents in the copper sheath. As the copper sheath has a low resistance and is not laminated these induced currents may be very large. The energy of the magnetic field is therefore largely expended in inducing eddy currents, and less is then available to react on the applied E. M. F. Under these conditions the reactance is a minimum. The current will have varying values when *S* is in intermediate positions.

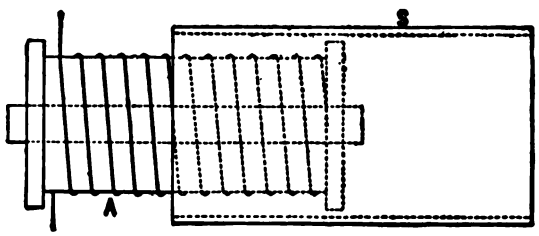


Fig. 3.

Choking coils are constructed on both of the above principles. The form shown in Fig. 2 is preferable as the only energy then consumed is by hysteresis of the iron core. With the form shown in Fig. 3, however, energy is also consumed in setting up eddy currents.

The most common use of choking coils is in electric light work. By the insertion of such a coil in their circuit, incandescent lamps may be "dimmed" or their light reduced to any desired extent. Inaccessible lamps in theatres, halls, etc., are lowered in brilliancy by this method. The same results may be obtained by inserting resistance in series with the lamps but much energy is then wasted by useless heating. Choking coils, however, reduce the current by absorbing but little energy.

**Phase Difference.** Self-induction in a circuit is greatest when there is the most rapid change in the current strength, and is not present when the current remains constant. The curve *C* in Fig. 4 represents the changes of an alternating current. It is evident that the most *abrupt* change occurs when the current is changing from positive to negative or from negative to positive, as at points *c* and *e*. The rate of change is less as the maximum values represented by *b* and *d* are approached, and *at* these points the change in current strength is zero. It therefore follows that self-induction represented by the dotted curve *E*, is a maximum when the current has zero strength and is zero when the current is a maximum. That is, at the points *a*, *c*, and *e*, etc., the opposing E. M. F. is a maximum, and at *b*, *d*, etc., it is zero. It is consequently out of step with the current by a difference of 90°. This is known as the *phase difference* by which the opposing E. M. F. follows the current. If two waves had maximum values at the same time and were exactly in step with each other at all times, they would then be in the same phase. If they exactly opposed each other at all times the phase difference would then be 180°.

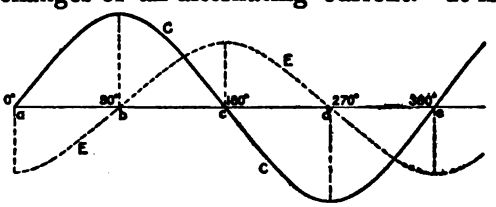


Fig. 4.

**Lag of Current.** From the preceding paragraph it is evident that the opposing E. M. F. due to self-induction, is always 90° behind the current. The effect of this phase difference is to cause the current to *lag* behind the applied E. M. F., as the current is dependent upon both the impressed E. M. F. and the E. M. F. of self-induction. This lag is illustrated in Fig. 5; the full line representing the current curve and the dotted line the curve of applied E. M. F. When the applied E. M. F. is zero, as at *b*, the current still has a certain value, and does not become zero until the applied E. M. F. has a value represented at *c*. This *lag* of the current is the same throughout the cycle and is represented in degrees by the distance *b c*. In the case illustrated the lag is 15°. The more self-induction in a circuit the greater becomes the lag of current behind the E. M. F. Self-induction therefore, not only reduces the strength of the current but also causes this lag.

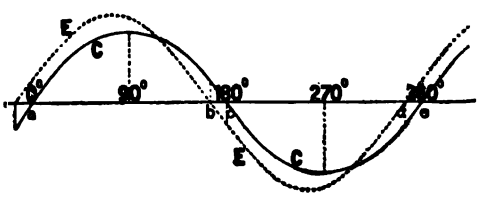


Fig. 5.

Self-induction is nearly always present to a greater or less extent in practical circuits. A load consisting of incandescent lamps or of a water resistance causes little or no self-induction, whereas, arc lamps and motors cause considerable. As inductance is greater when the *rate* of change in current strength is increased, it is evident that the higher the frequency the greater the self-induction.

**Effect of Capacity.** When there is capacity in the circuit it causes the opposite effect of inductance. That is, the presence of capacity tends to *hasten* the increase and decrease in current strength and produce a *lead* in the phase of the current. If there are both capacity and inductance present they will tend to neutralize the effect of each other, and it is possible to arrange a circuit so that the capacity and inductance will balance exactly. In practice the presence of capacity is of little moment as compared with inductance. Attempts have been made to introduce capacity in practical circuits so as to neutralize the inductance, but the methods used have not yet been successful enough to cause their adoption.

**Power in an Alternating Current Circuit.** The voltmeter and ammeter readings obtained from an alternating current circuit give the *virtual* volts and amperes. If the E. M. F. and current are *in phase* with each other, the power expended in watts is given by the product of the voltmeter and ammeter readings. If they are *out of phase* this product will be greater than the true watts and is consequently called the *apparent power* or *apparent watts*. The greater the phase difference the less is the actual power developed in a circuit. The inductance in a circuit may be so large that the apparent power is two or three times the actual power.

In order that a current may do work there must be a certain pressure or E. M. F. acting in the same direction with it. If this pressure opposes the current, work is then done upon the current, that is, work is absorbed. The fact that lag of current reduces the true power may be understood from Fig. 5. Between the points *a* and *b* the E. M. F. and current are *both* positive and work is then being done. Similarly between points *c* and *d* work is also being done since the E. M. F. and current are *both* negative. On the other hand, between the points *b* and *c* and between *d* and *e*, the E. M. F. is opposite in sign to the current. The E. M. F. acting against the current then causes the *absorption* of work. A cycle may therefore be considered as divided into four parts. In two of these parts work is being done, while in the other two work is absorbed. The actual work done is therefore the difference between them. It is evident that the greater the lag the longer will be the periods of absorption and the shorter the periods of doing work. If the lag were 90°, the periods of absorption and of doing work would be equal, and the resultant power would be zero. A current lag of 90° is practically impossible, but by making the reactance in a circuit large and the conductor resistance small, as in the choke coil, a lag very near 90° is obtained.

The ratio of the true to the apparent watts is called the **power factor.** The true watts are directly obtained by means of a non-inductive wattmeter.

Example. — The current and E. M. F. of an alternator as given by an alternating current ammeter and voltmeter was 32

amperes and 2,000 volts respectively. A wattmeter indicated the true power to be 51,200 watts. What was the power factor?

Solution. — The apparent power is the product of the virtual volts and amperes, therefore

$$\textit{apparent power} = 2{,}000 \times 32 = 64{,}000 \text{ watts.}$$

The power factor being the ratio of the true to the apparent power, we have

$$\textit{power factor} = \frac{51{,}200}{64{,}000} = .8$$

Ans. .8

In practical work it is very important to keep this power factor as near unity as possible.

**Wattless Current.** In order to make a distinction between the true and apparent watts it is customary to consider the current as resolved into two parts. One part is assumed to be in phase with the E. M. F. and is known as the *working* current. The remaining part is assumed to be always 90° behind the E. M. F. and therefore not effective in doing work. This is called the idle or *wattless* current.

## ALTERNATORS.

An alternating current generator is commonly called an alternator. These machines are generally made multipolar on account of the *frequency* required in practice. This ranges from 40 to 140 cycles per second, but commonly is between 60 and 135. A frequency of less than 40 cannot be used for arc lamps, and frequencies much over 100 are objectionable on account of excessive inductance. A bipolar machine must have 3600 revolutions per minute to attain a frequency of 60 and this would give too high a peripheral speed in machines even of moderate size. If four poles are used the speed can then be reduced to 1800 revolutions. Usually alternators have from 8 to 48 or more poles.

## WINDINGS OF ARMATURES.

The armatures of alternators have the same general forms as those of direct current machines, but the methods of winding and connecting are quite different. The armature may revolve and the fields may be stationary, or the fields may revolve and have the armature stationary.

**Ring Armatures.** Fig. 6, which represents a section of a multipolar alternator, shows a method of connecting the armature coils in series. The dotted lines represent the lines of force of the field. It will be noted that each coil is wound about the ring in opposite direction to adjacent ones. That is, all coils which are about to pass under south poles are wound in the opposite direction to those about to pass under north poles. The induced currents are thus made to flow in the same direction in all the coils at any instant. If the coils were wound in the same direction, as in the direct current machine, the E. M. F. generated by one set of alternate coils would oppose that generated by the other, and the resultant effect would be zero.

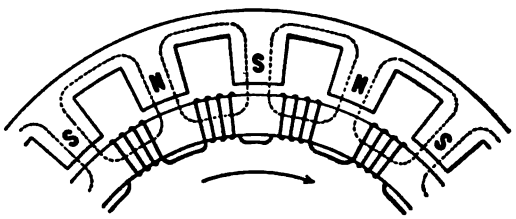


Fig. 6.

It will be further noted that the width of each coil is about equal to that of the pole faces. When the coils are in the position shown they are then moving parallel with the lines of force and no E. M. F. is generated. When the coils are opposite the poles, the maximum E. M. F. is produced. If the coils extended beyond the width of the poles, and closed up the open spaces, only the windings immediately opposite the poles would be effective. Any additional winding would be outside the magnetic field, and therefore be useless resistance.

When the armature moves from the position shown, part of the windings begin to be effective and the E. M. F. gradually increases to a maximum. On further motion part of the windings cease to be effective and the E. M. F. gradually decreases to zero. The coils then begin to cut lines of force passing in an opposite direction and the reversed E. M. F. gradually rises to a maximum and decreases to zero. The continuance of the motion causes similar changes.

Fig. 7 shows the method of connecting coils which are wound in the same direction about the ring. The direction of the induced currents in the coils is then the same.

Ring armatures have the objection of considerable self-induction in the windings, and require more wire than drum armatures for a given output. When the ring encircles the fields, as in the Siemens and Halske machine, the speed of the armature may be comparatively slow.

**Collecting Rings and Connections.** By connecting all the coils in series the E. M. F. has the highest value possible. In order to conduct the current from the armature to the external circuit, it is only necessary to connect the two leads from the armature to two *collecting rings* or *collectors*, mounted on the shaft with the armature. Brushes may then maintain sliding contact with them and conduct the alternating current to the external circuit. These rings, which are made of copper or bronze, are undivided and well insulated from each other.

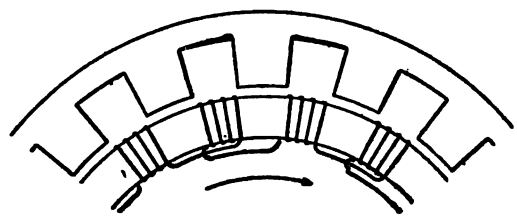


Fig. 7.

When all armature coils are connected in series, it causes two coils to be side by side having the maximum difference of potential between them. If the E. M. F. of the machine is high, as is usually the case, it becomes difficult to insulate these end coils. It is usual, therefore, to subdivide the armature circuit so that the halves of the windings are connected in parallel. The maximum difference of potential then occurs between two points diametrically opposite; and good insulation is more easily secured. The E. M. F. of the machine is then only one-half of what it is with all the coils connected in series. By further symmetrical connections the number of coils in parallel may be increased, and the voltage of the machine correspondingly lowered.

**Drum Armatures.** Drum windings of alternators are more common than ring windings. The core is usually a ring, however, which is of sufficient cross-section to conduct the magnetic lines. Fig. 8 shows the lapped ends of a drum winding. The coils *A*, *B*, *C*, etc., lie flat on the surface of the core. As a coil so placed must have half its wires passing in one direction and half

in the other, they can all be active and generate an E. M. F. in the same direction in the wires, only by having half the coil under a north pole and half under a south pole. There is then an open space between the poles. The right-hand half of coil *A* for example, is under a south pole and the left under a north pole. The current in the right-hand half will be opposite in direction to that in the left-hand half, since the direction of the magnetic field through which they are passing is opposite. The two sections, therefore, do not oppose each other. The separate coils must likewise be inter-connected so that they may not be in opposition. In the position shown the maximum E. M. F. is generated. When the spaces are opposite the poles, no E. M. F. is generated and on further motion the maximum E. M. F. is generated in the opposite direction. Fig. 9 illustrates diagramatically the connections of the coils of a drum armature where there are as many coils as poles and where the halves are connected in parallel.

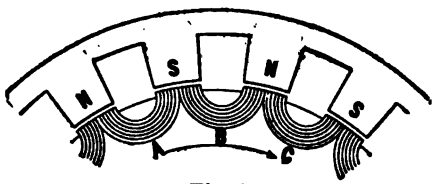


Fig. 8.

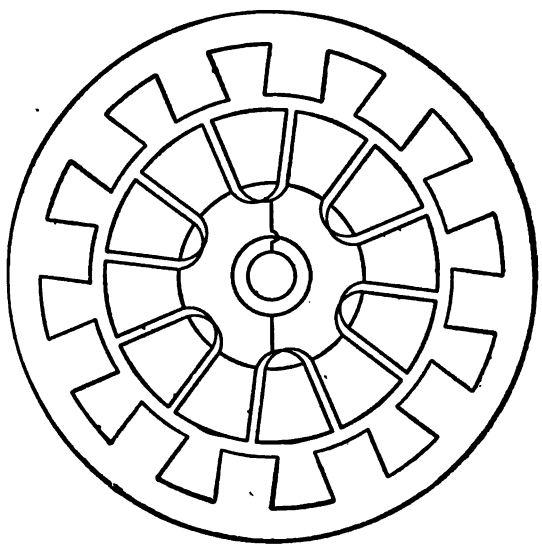


Fig. 9.

Drum armatures have the advantage that the coils may be machine wound and then applied to the armature core. If a smooth core is used, it is customary to fix strips of wood within the coils, which then serve as driving teeth and give a smooth exterior surface to the core. Owing to the high peripheral velocity of alternators, heavy band wires are required for surface wound armatures. Toothed cores have the advantage

**700 H.P. INDUCTION MOTOR**
**Manufactured by General Electric Company**

that they permit the use of a small air gap and provide an excellent support for the coils as well as giving them mechanical protection. The use of toothed cores however, increases the armature reaction and self-induction. The number of teeth is made equal to the number of coils.

**Disc Armatures.** Some machines, notably those built in England, have disc armatures. Such an armature consists of thin flat coils mounted on the periphery of a thin disc. These revolve between two sets of field magnets, which have unlike poles opposite each other as shown in Fig. 10.

As the disc armature has no iron core, it possesses the advantages of being free from hysteresis and eddy current losses. Such

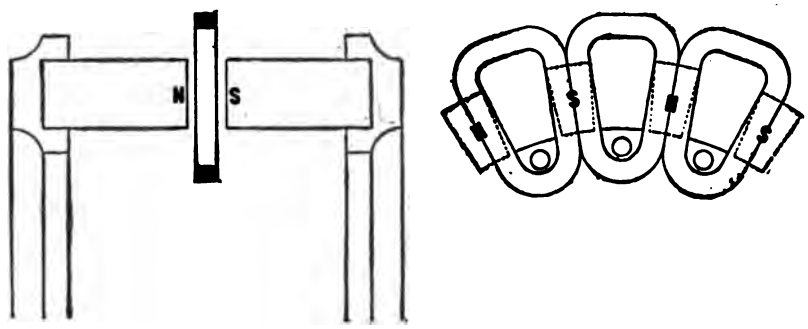



Fig. 10.

armatures are also cool running and the coils may be easily replaced or repaired. There is, however, some difficulty of supporting the coils in a substantial manner, causing them to be expensive to build.

**Field Excitation.** As the alternating current cannot be used to excite the field magnets of a machine, the question of field excitation of alternators proves to be more difficult than with direct current machines. The usual method of accomplishing this is to supply the alternator with an auxiliary direct current dynamo, which is called its **exciter.** This is a small machine and is sometimes mounted on the same shaft with the alternator, but is more often driven by a belt from the shaft. The exciting current may be regulated by adjusting a resistance inserted in series with the exciting circuit.

In order that constant potential machines may be self-regulat-

ing, a series winding is necessary. On account of self-induction and demagnetizing action of the armature, greater excitation is required at full load than at no load. The main current of the alternator therefore, is passed through the series winding, but it must of course be commutated and always have the same direction in passing through the series winding. For this purpose a commutator is used, which causes the current to be direct but at the same time constantly fluctuating from zero to a maximum.

The number of segments in the commutator is equal to the number of poles on the machine. The commutator for an eight-polar alternator is illustrated in Fig. 11. The alternate segments are electrically connected, thus making two sets. To each of these, one of the alternating current leads is connected. The brushes *A* and *B* conduct the rectified current to the series field windings. With eight poles there will be eight alternations per revolution and each segment will change from + to — eight times. When one set of segments is positive the other is negative. The positive brush *A*, is in contact with segments *P* only when they are positive, while *B* is in contact with segments *K* only when they are negative. Hence when *P* changes from + to — it passes from under *A* and makes contact with *B*, and *K* now becoming positive makes contact with *A*. The direction of the current from *A* to *B* through the field coils will therefore be unchanged.

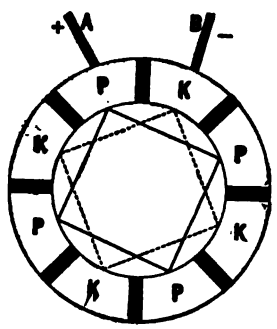


Fig. 11.

The connections for a compound wound alternator, having separately excited shunt coils and self-excited series coils are shown in Fig. 12. In this case the full armature current is rectified and passed through the series coils. The course of the current is from the external circuit at *A* to the collector ring *B*; through the armature coils in series to the rectifying commutator *C*; through the series field coils to the commutator *C* again, to the collector ring *D* and then to the external circuit. The series winding may consist of a few turns on each of the poles or all of the turns may be confined to one or two of the poles. When the armature winding consists of two circuits connected in parallel,

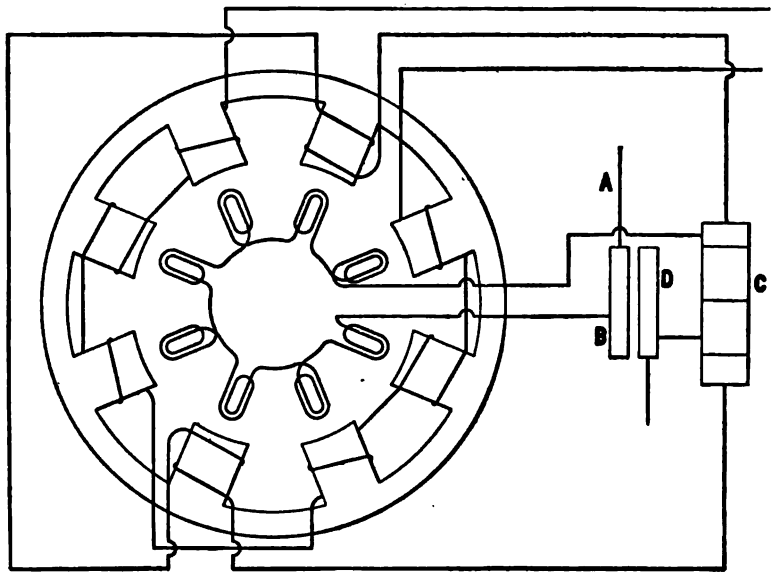



Fig. 12.

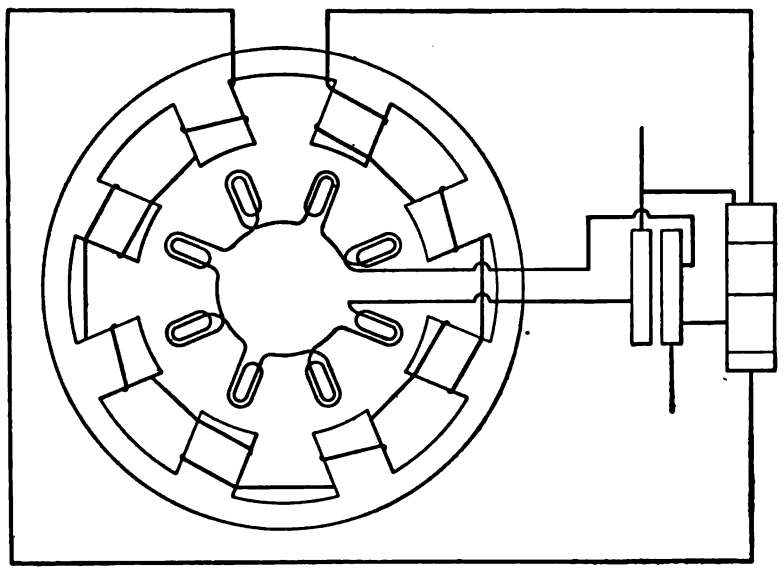


Fig. 13.

the series turns are always equally divided between the halves of the field.

Some machines are arranged with a special transformer attached to the armature, the current from the secondary being rectified and used to excite the fields. The strength of this current will vary directly as the load on the alternator and thus compensate for varying losses.

Alternators having only series or shunt coils are sometimes made self-exciting, the latter being the more common. The total E. M. F. of the machine may be impressed upon the shunt coils or the E. M. F. may be reduced by means of a transformer attached to the armature. The connections of a self-exciting shunt machine are shown in Fig. 13, the full E. M. F. being impressed upon the shunt coils.

## REGULATION.

The regulation of a separately excited alternator is usually accomplished by means of a hand regulator either in the field circuit of the shunt-wound exciter or directly in series with the alternator fields. Self-excited shunt-wound alternators are also regulated by a variable resistance in the exciting circuit which is adjusted by hand. In compound-wound alternators the number of self-excited series turns is made such that the external characteristic is a horizontal or slightly rising line. The magnetizing effect is sometimes varied by connecting a variable shunt circuit around the series field windings.

When several feeders receive current from one source of supply, the potential at the different receiving stations is likely to show considerable variation, depending upon the load upon the feeders, and their length and cross-section. With incandescent lamps it is especially important that the potential at all the lamps of a system should be uniform. If one generator supplied a single circuit the drop in the line could be compensated for by regulating the potential of the alternator. In case two or more circuits are supplied by the same machine, and the E. M. F. is adjusted to suit the requirements of one of them, then, unless the drop in all circuits is the same, the voltage at the lamps on the different circuits will vary considerably. There are several forms of alter-

nating current devices for regulating the pressure on the separate feeder circuits. These regulators are connected in series with the separate feeders and raise or lower the voltage of each as required.

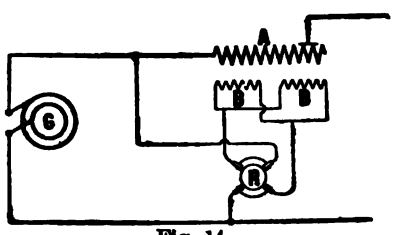


Fig. 14.

The Stillwell regulator, manufactured by the Westinghouse Company, is primarily a transformer, consisting of two induction coils. One of the coils *A*, as indicated in Fig. 14, is connected in series with one of the feed wires from the alternator *G*, while the other *B*, consisting of two parts connected in parallel, is shunted across the mains, through a reversing switch *R*. The induction through the primary coil *B* induces an E. M. F. in the coil *A*, and this, added to the impressed E. M. F., raises the potential of the feeder, although that of the alternator remains the same. The greater the number of turns in the coil *A* the greater will be the induced E. M. F. Changing the number of effective turns by means of movable contacts varies therefore, the E. M. F. of the feeder. The potential of the alternator is usually adjusted to meet the average requirements of the several circuits, and the regulators are used to increase the potential of those circuits for which the generator potential is too low, and to lower the potential of those circuits for which the generator potential is too high. For these reasons the regulator is supplied with a reversing switch, and when the current is sent through the coil *B* in a reverse direction, an opposing E. M. F. is generated in coil *A*, which reduces the potential of the feeder.

The voltage of the distant ends of the feeder is indicated by a compensating voltmeter. The voltmeter *V*, as shown in Fig. 15, is connected in series with the secondary circuits of two transformer coils *A* and *B*. The coil *A* has its primary circuit *C* shunted across the mains, while the primary coil *D* is connected in series with the feeder circuit. The E. M. F. induced in the coil *A*

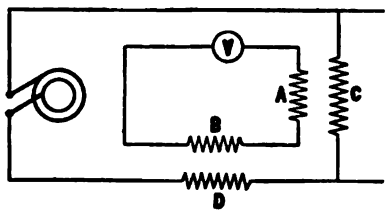


Fig. 15.

is proportional to the potential of the generator. The E. M. F. induced in coil *B* is proportional to the current in the feeder, and as coil *B* is made to oppose coil *A*, the greater the feeder current the more reduced will be the voltmeter reading. It is possible to adjust the coils so that the decrease in the voltmeter reading will be equal to the drop in the feeder. The voltmeter therefore, will indicate at all times the voltage at the distant end of the feeder. Such an arrangement eliminates the necessity of running voltmeter or pressure wires from the end of the feeder to the station.

**Coupling of Alternators.** Two or more direct current dynamos may be operated with but little difficulty when connected either in series or in parallel. With alternating current machines, however, special conditions are required for their successful operation. In order that the output of one machine may be *added* to that of another, it is necessary that the electromotive forces of each machine should be in exact agreement. The machines must have therefore, equal frequencies, and also be *in phase* or *in step* with each other.

**Series Coupling.** It is not possible to operate two alternators in series when they are driven independently, if there is any inductance in the circuit. If the armatures of two alternators, having the same frequency and E. M. F., are connected in series, the resultant pressure of the two machines will be equal to their algebraic sum. If the machines are out of phase with each other, the *resultant* pressure will lag behind the E. M. F. of the leading machine to the same extent that it leads the E. M. F. of the lagging machine. Inductance in the circuit will cause the current passing through the two machines to lag behind the resultant E. M. F. This will cause a *small* difference in phase between the current and the E. M. F. of the lagging machine compared with the phase difference between the current and E. M. F. of the leading machine. The less the phase difference between current and E. M. F. the greater is the amount of work. As the lagging machine is nearer in phase with the current, more work will then be done by this machine than by the other. The lagging machine, being the more heavily loaded, will be unable to keep up with the machine doing the smaller amount of work, and therefore tends to lag or fall behind more and more. This will continue until the

two machines come into opposition, when no work could be done in the external circuit. If the machines could be brought into perfect agreement an equal amount of work would be done by each. Their equilibrium however, would be unstable, and their operation would not be practical, unless the machines were rigidly connected.

**Parallel Coupling.** Usually, alternators may be operated in parallel with but little difficulty. As shown in the preceding paragraph, if two alternators are connected in series there is a constant tendency for them to assume complete opposition. If we neglect the external circuit, *L* in Fig. 16, the alternators *A A* may be considered as connected in series. Being in series the machines will come into opposition and the brushes which are connected with each other will always have the same potential. When the upper brushes are positive the lower ones will be negative, or with the lower brushes positive the upper ones will be negative. If then, an external circuit *L* is connected as shown, the alternators will be connected in parallel and will supply equal currents to the external circuit. There will be no tendency of the alternators to get out of phase, and if out of phase at any time the tendency will be to come into agreement.

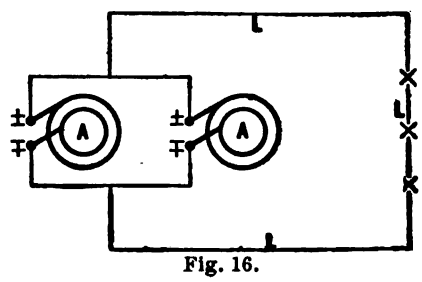


Fig. 16.

Usually machines of the same make will operate well in parallel, and some machines will operate much better than others. This method of operating alternators is much more prevalent in Europe than in America. In this country it is common practice to operate the alternators independent of each other, especially in small stations. In order that the alternators may be fully loaded, and therefore run at a high efficiency, it is customary to arrange the switchboard connections so that any feeder may be connected to any alternator. Hence, as the load decreases, one alternator may be stopped and its load transferred to the machines which are still running. With this arrangement no one feeder can be designed to carry a load greater than the capacity of a single

machine. It is very probable that the increase in number of large central stations and the lessened difficulty of operation in parallel, will cause this method to become more common in this country.

**Synchronizers.** In order that the strain put upon the generating apparatus may be as small as possible when one machine is thrown in parallel with another, it is important that they should first have the same speed and be in phase with each other, that is, they must be in synchronism. By connecting the machines at such a time, there is but little disturbance of the other alternators. A device for indicating the synchronism of two or more machines is called a *synchronizer* or *phase indicator*.

The most common form of synchronizer consists of an incandescent lamp so connected in relation to the alternators, that their synchronism is indicated when the lamp is at its full brilliancy or when it gives no light whatever.

The principle of a synchronizer will be understood from Fig. 17. Suppose alternator *A* is already connected to the external circuit and alternator *B* is to be thrown into parallel with it. Alternator *B* is first brought up to a speed which corresponds very nearly with that of *A*. When the machines are in phase with each other, the two lower brushes will have the same potential at the same time. The potential difference between the terminals of the incandescent lamp *L* will then be zero, and the lamp will be dark. When the machines are in opposite phases, the lower brush of *A* will have an opposite potential from that of *B* and as a current will then flow through the lamp it will have its maximum brightness. If the alternators have different speeds, their phase relation will be changing constantly and the lamp will glow and darken alternately. The greater the difference in speed, the more rapid will be the fluctuations in the lamp. When these fluctuations become slow and definite, it indicates that the speeds are very nearly the same. With the lamps connected as shown, alternator *B* should be switched on to the circuit at an instant of *no* illumination. The

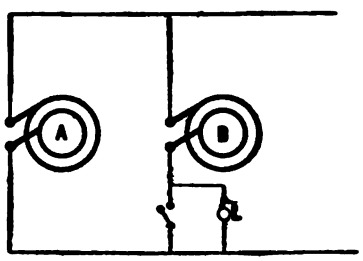
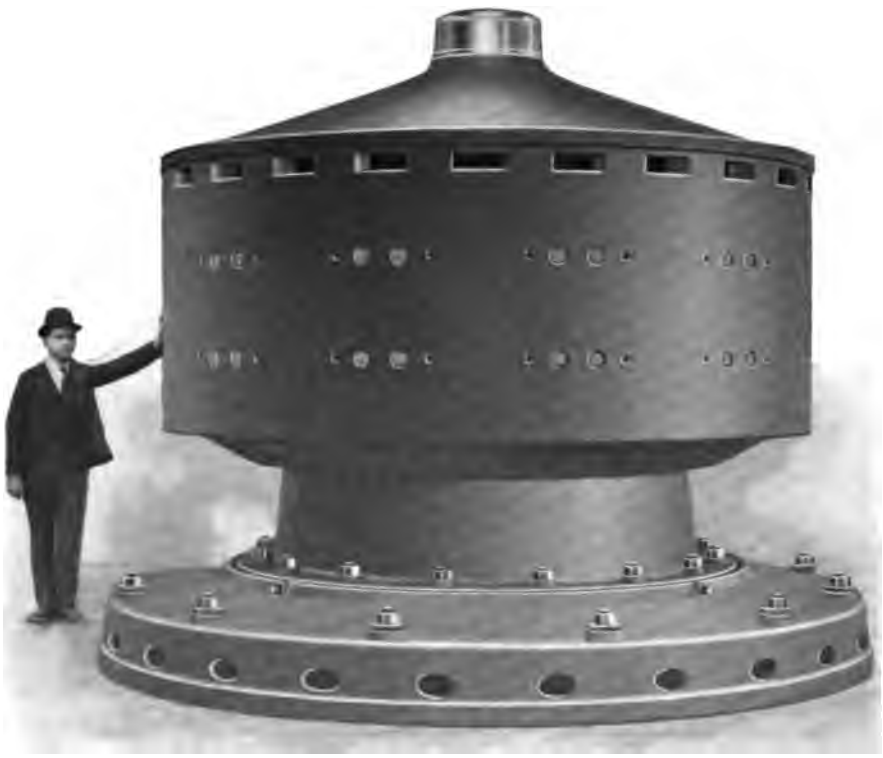


Fig. 17.



**ALTERNATING CURRENT GENERATOR**

**Manufactured by General Electric Company for Niagara Falls Power Company**

**Capacity, 3750 Kw. at 2200 Volts**

machines will then come into synchronism. As the voltages of alternators are usually high, it is customary to reduce the voltage applied to the lamp by means of a transformer. Fig. 18 shows a common arrangement in which two transformers are used. The induction coil *C* of one transformer is connected across the circuit. The coil *D* of the other transformer is connected across the terminals of the alternator which is to be switched on the circuit. The current in coil *C* induces a current in coil *E*, which is not however,

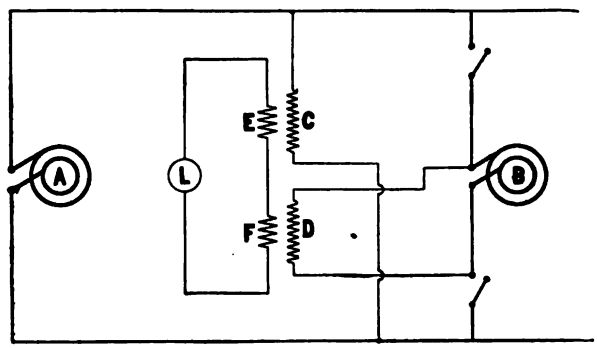



Fig. 18.

strong enough to cause the lamp *L* to attain its full brilliancy. When alternator *B* is brought up to speed a current will flow in *D* which will in turn induce a current in coil *F*. When the two alternators are in phase, the induced currents in *E* and *F* will assist each other and the lamp will then have its maximum brightness. When in opposite phases the lamp will be dark.

Darkness of the lamp may be made to indicate synchronism, either by connecting the coils *E* and *F* so as to oppose each other, or by connecting the coils *C* and *D* in a similar manner. As it is difficult to distinguish between different degrees of brightness, it is more often the custom to connect the phase indicator so that darkness will show when the machines are in phase.

## INDUCTOR ALTERNATORS.

Within recent years this type of alternator has been developed considerably. The field and armature windings are both stationary and the induction through the armature coils is varied by the revolution of magnetized masses of iron called *inductors*. These machines have the advantage of requiring no collecting

devices, little attention during operation, and as the armature is stationary, excellent insulation can be obtained. This permits the generation of a higher E. M. F. than is possible with revolving armatures.

A form of inductor is shown in Fig. 19. The armature coils are wound upon the internally projecting poles of the external ring. The rotating part is magnetized by the stationary field coil *A A*, which is separately excited with a direct current. As the inductor is magnetized by a single stationary coil, the pole pieces *N* are always of the same polarity. The rotation of these

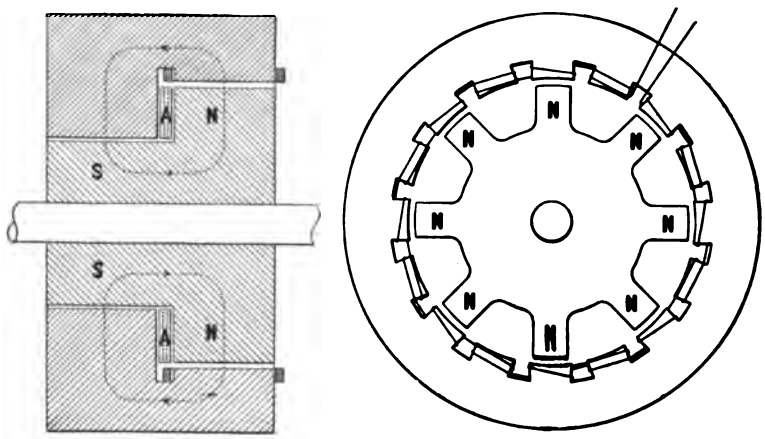


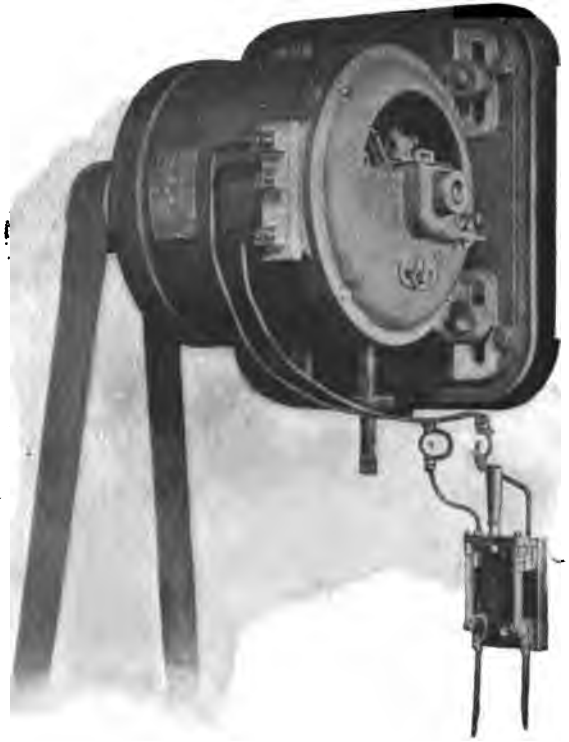

Fig. 19.

magnetized poles opposite the armature windings, causes a gradual insertion and withdrawal of the magnetic lines through the armature coils, each time a pole passes. As the windings of adjacent armature coils are reversed in direction, an alternating current is produced.

The inductor and armature ring are usually made of cast steel with laminated pole pieces. It is important that the end *S* of the inductor should be accurately fitted to the circular frame in order that the air gap, and consequently the magnetizing force required, will be as small as possible.

Another form of inductor alternator is shown in Fig. 20. The inductor is magnetized by the fixed coil *A A*, producing north poles *N* on the right, and south poles *S* on the left. The armature

## THE SINGLE-PHASE SELF-STARTING ALTERNATING CURRENT MOTOR.



2 H. P. Single-Phase Self-Starting A. C. Wagner Motor, Inverted Position.

Single-Phase Self-Starting A. C. Wagner Motor, Attached to Wall.

windings consist of two series of armature coils opposite the two series of inductor poles. The magnetic circuit is indicated by the dotted lines.

Fig. 21 shows part of an inductor alternator in which the

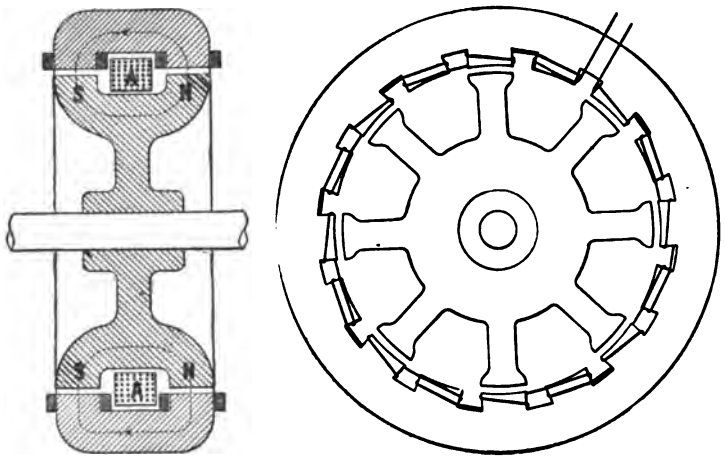



Fig. 20.

magnetism of the inductor is constantly changing. The alternate poles of the ring receive a constant magnetization by separately excited coils which produces north and south poles as indicated. The poles *A* are wound with coils which form the armature winding. The inductor consists of revolving blocks of laminated iron *L*. The magnetic circuits are represented for two different positions when the magnetic flux through the armature coils is a maximum. In the different positions of the inductor shown, the direc-

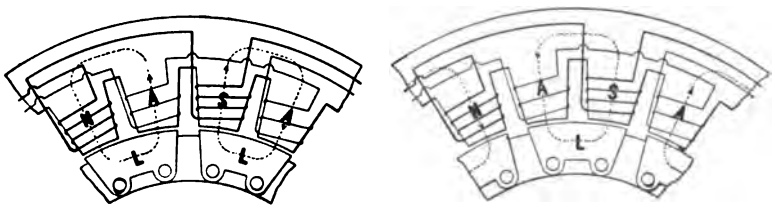



Fig. 21.

tion of the flux is evidently opposite through these coils. For the intermediate positions there is a gradual change in the strength of the magnetic flux through the armature coils thus producing an alternating E. M. F.

Inductor alternators have the disadvantage of being subject to excessive hysteresis and eddy current losses unless the iron parts, in which the magnetic flux is variable, are well laminated.

## MULTIPHASE ALTERNATORS.

Alternators which supply only a single current to the external circuit, such as we have already considered, are known as single-phase machines. Those supplying two or more currents, which differ in phase from each other, are called *polyphase* or *multiphase* machines. Generally either two or three currents are supplied, and such machines are known as *two-phase* and *three-phase* alternators respectively.

**Two-Phase Alternators.** We have seen that with a single-phase machine only about half of the armature surface can be wound with wire. The output of such a machine can be increased by winding an additional circuit on the armature, which shall occupy the vacant space. Referring to Fig. 6, it is evident that with an additional winding between the coils shown, the added coils would be in a position to generate a maximum E. M. F. when the other coils are not cutting lines of force. Also when the latter are generating a maximum E. M. F., that produced by the added coils will be zero.

The phase relation of the currents supplied to their two external and independent circuits is shown in Fig. 22. The curve *A* represents the value of the current given by one armature circuit and curve *B* that given by the other, one curve having a maximum value when the other is zero. As one complete cycle is developed in 360°, it is evident from Fig. 22, that the phase difference between the two curves *A* and *B* is 90°.

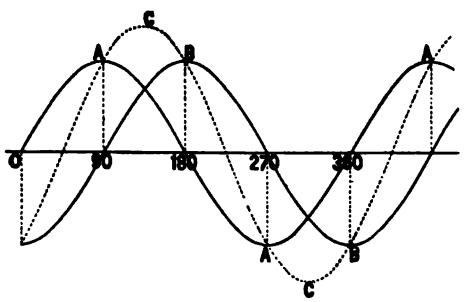


Fig. 22.

If the two armature circuits are independent, there must be four external wires and four collecting rings. It is, however, possible to combine the windings so that only three collecting

EUROPEAN TYPE OF DIRECT DRIVEN ALTERNATOR

rings and three external wires will be required. This form of connection is shown in Fig. 23, the wires $K$, $L$, $M$ leading to the external circuit. Wire $L$ acts as a common return or supply for the two outside wires, and its current at any instant is equal to the algebraic sum of the currents in the other two wires. The strength of this current is shown by the dotted curve $C$ in Fig. 22. It is evident that this current differs in phase from the current in the outside wires by 45°, its maximum value occurring 45° ahead of the maximum value of one and 45° behind the maximum of the other. Also the current strength in the common wire is equal to $\sqrt{2}$ or 1.4 times the current strength in the outside wires.

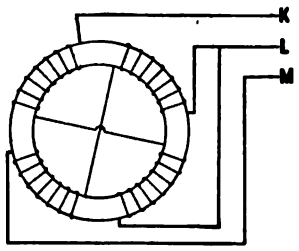


Fig. 23.

If the potential difference between the wires $K$ and $L$ and between $M$ and $L$ is equal to $E$, then the potential difference between $K$ and $M$ is equal to $1.4 \times E$.

**Three-Phase Machines.** An alternator may be so arranged that the armature will supply three currents to the external circuits, all differing in phase. The windings may be entirely independent of each other, in which case six external wires are required. In almost all cases, however, the three windings are combined so as to require only three external wires. The windings are placed on the armature in such a manner, that each winding successively supplies the maximum current. This is illustrated in Fig. 24, which represents the values of the three currents in the armature windings. It is evident that there is a phase difference of 120° between the maximum value of each curve, and also that the amount of current flowing in one direction is at all times equal to the amount flowing in the opposite direction. When one current has a maximum value, the currents in the other two windings are opposite in direction and each equal to half their

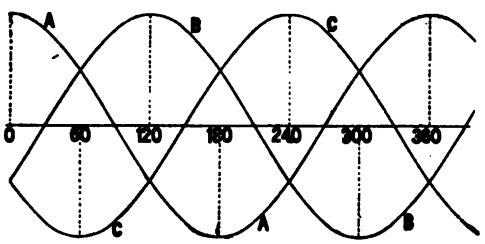


Fig. 24.

maximum value. At intermediate points it is evident that the sum of the ordinates on one side of the horizontal line is always equal to the ordinate of the curve on the other. It is due to this property of the three-phase system that the armature windings may be connected so as to require only three external wires and three col-

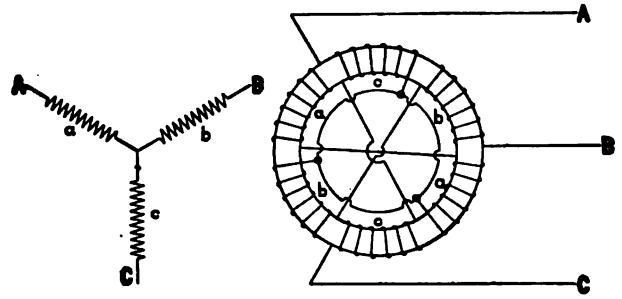



Fig. 25.

lector rings. One of the wires then acts at any instant as a common supply or return for the other two.

There are two general methods of connecting the armature windings of three-phase generators. These are called the *star* and the *mesh* connections. All three-phase windings are of one form or the other or a combination of both.

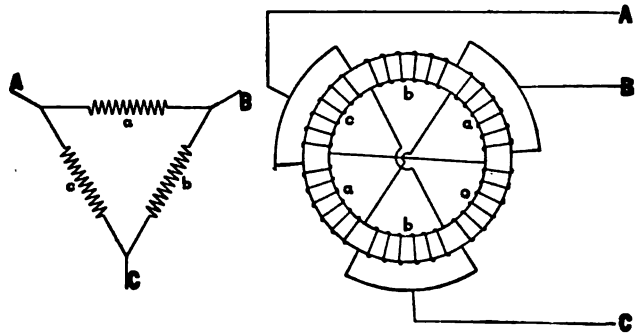



Fig. 26.

Fig. 25 illustrates the star form of winding. The wires from the external circuit lead through the three windings to a common electrical connection. Fig. 26 illustrates the mesh winding, in which the ends of the three windings are joined and the external wires connected to their junction. The diagrams at the left in

Figs. 25 and 26, indicate at a glance the method of connecting the coils and is the usual form of representing the windings.

These two methods of connecting bring about considerable difference in the value of the E. M. F. or current in the external circuit. From Fig. 25 it is evident that the current in the coils *a*, *b* and *c* must be the same in the external wires. The potential difference between any two of the external wires must be a combination of the instantaneous values of the E. M. F. generated in the coils *a*, *b* or *c*. If the E. M. F. generated in each coil is *E*, then the potential difference between *A* and *B*, *B* and *C*, or between *C* and *A* is equal to $\sqrt{3} \times E$. In the mesh winding it is evident from Fig. 26 that the potential difference between the external wires is equal to the E. M. F. generated in the coils *a*, *b* or *c*. The current in the external wires however, is a combination of the currents in the coils to which each external wire is connected. If the current in each coil is *I*, then the current in each of the external wires is $\sqrt{3} \times I$.

The special application of two and three-phase windings to induction motors is considered on following pages.

## TRANSFORMERS.

The extensive development of the alternating current system for transmitting power long distances is largely due to the ease with which the voltage may be regulated to suit the conditions and the small losses involved. The higher the voltage of transmission the less will be the line loss, and the smaller may be the size of the conductor. Transformers are therefore very extensively used to raise the voltage if necessary at the generating station, giving a high line voltage, and to lower it at receiving stations to safe voltages for general use. Except for long-distance working, alternating current generators are usually made to generate a voltage as high as is required for the line. It is then necessary merely to lower the voltage at the receiving station.

We have seen that when two coils are placed so that the magnetic flux of one passes through the other, an E. M. F. is induced in the latter whenever the strength of the current in the first coil is varied. If the coils are supplied with an iron core, the eluctance of the magnetic circuit through the coils will be very

much reduced, and the flux consequently much increased. This will greatly increase the efficiency of the apparatus. Such an arrangement constitutes a transformer, and is in reality an induction coil. The coil to which the original energy is supplied is called the *primary coil*, while that in which the currents are induced is called the *secondary coil*.

The core always consists of a closed circuit of iron, and of such a shape that the magnetic lines created by the primary coil pass with a minimum amount of leakage, through the secondary coil. To increase the magnetic flux as much as possible with a given current, the core is made compact and with but few joints. The reluctance is also decreased by having the core of ample cross-section and by the use of iron having a high permeability. As the magnetization of the iron is constantly undergoing changes in its strength, it is important that the hysteresis of the iron should be low. The iron must be laminated to avoid as far as possible, the generation of eddy currents caused by the rapid changes in strength and direction of the magnetism.

Fig. 27 illustrates an elementary transformer. The alternating current passing in the primary coil $P$ causes the magnetic flux of the iron core to vary in a similar manner. The passing of these magnetic lines through the secondary coil $S$ generates in it an E. M. F., whose value depends upon the number of turns of wire about the core. If the secondary coil consists of many turns, then this circuit is cut a large number of times by the magnetic flux and its E. M. F. will be high. If the secondary has the same number of turns as the primary, nearly the same E. M. F. will be produced at the terminals of the secondary coil as applied to the primary coil; if the secondary has a larger number of turns, a higher E. M. F. will be produced. Moreover, neglecting magnetic leakage, the E. M. F. of the secondary is to the E. M. F. of the primary as the number of turns in the secondary is to the number of turns in the primary. For example, if the secondary has 10 and the primary 1000 turns, then the E. M. F. of the secondary

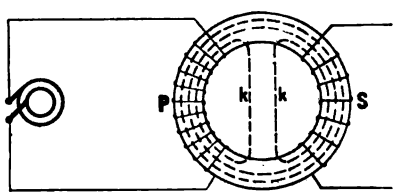


Fig. 27.

will be $\frac{10}{1000}$ or $\frac{1}{100}$ of the primary E. M. F. Thus if the primary E. M. F. was 10,000 volts, that of the secondary would be 100 volts. This decrease of E. M. F. will be accompanied by a corresponding increase in the secondary current. Except for slight losses in the transformer, the energy obtained from the secondary coil will equal that supplied to the primary, the energy in each case being proportional to the product of E. M. F. and current.

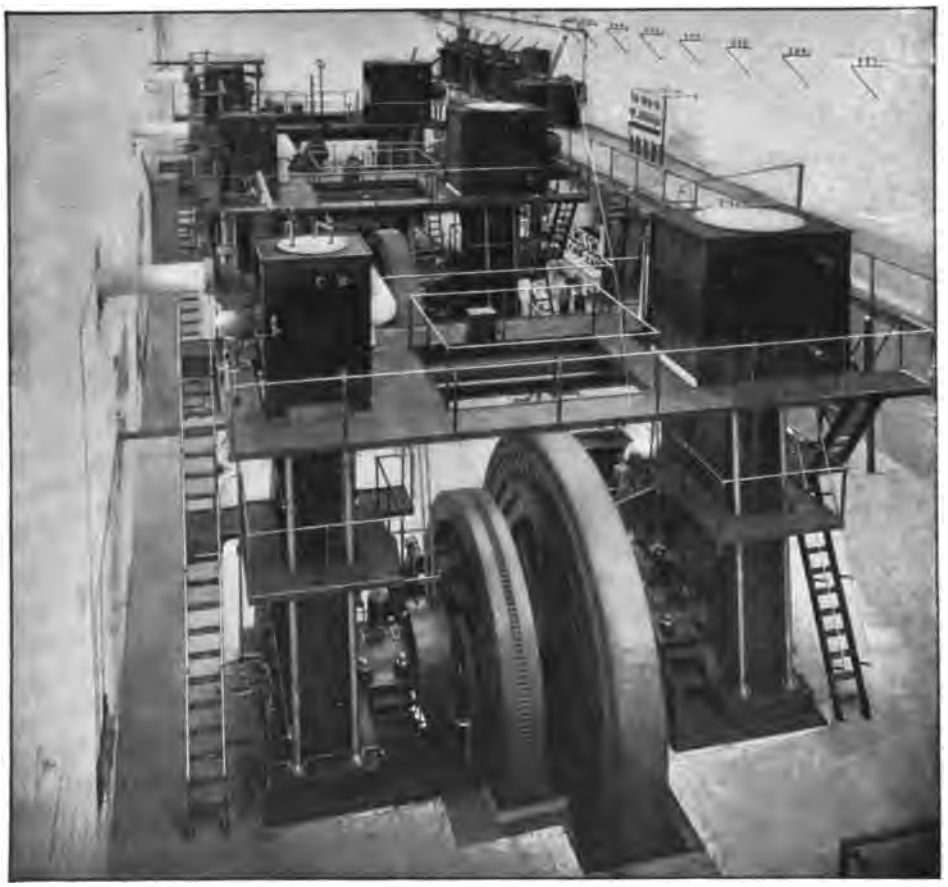
To more fully understand the action of a transformer, we will first consider the secondary circuit to be open. As no current will then flow in this coil, we may consider the action of the primary coil alone. Owing to the core of soft iron, the self-induction of the primary coil will be very great. Hence, with an open circuited secondary, the E. M. F. of self-induction will react upon the impressed E. M. F. and choke down the current. The transformer then acts as a choke coil, which has been described on preceding pages. The E. M. F. of self-induction will very nearly equal the impressed E. M. F. and therefore the current will be small. This current serves to magnetize the core and to compensate for hysteresis and eddy current losses.

Now suppose the secondary circuit to be closed. The current in this coil will be in opposite phase to that passing in the primary coil. That is, the current in the secondary will be opposite in direction to that in the primary, but both currents will increase and decrease together. Hence, while the tendency of the primary current is to magnetize, that of the secondary is to demagnetize the core. This demagnetizing tendency will thus reduce the magnetic flux through the core and consequently reduce the reactive E. M. F. of self-induction in the primary. This reaction being reduced, more current will flow in the primary and the flux will be increased to its original value. In this way the E. M. F. of the secondary coil is kept up, and the current in the primary, therefore, varies directly as the load on the secondary. If the E. M. F. of the primary circuit is kept constant, then that of the secondary will also be constant.

Magnetic leakage exists when magnetic lines which pass through the primary do not pass through the secondary, or when lines which pass through the secondary do not pass through the primary. The lines *k k* in Fig. 27 represent leakage lines. The

effect of magnetic leakage is to decrease the E. M. F. induced in the secondary. Suppose a current to be passing in the primary coil only. If magnetic leakage is present, then since less magnetic lines pass through the secondary than are created by the primary, it is evident that the E. M. F. of the secondary is less than would be the case if there were no leakage. When a current passes in the secondary, leakage will cause less flux, due to this current, to pass through the primary than passes through the secondary. The E. M. F. of self-induction of the secondary will therefore, be greater than the reaction on the primary, which will reduce still further the secondary E. M. F. Magnetic leakage may be eliminated almost entirely by winding the primary and secondary coils over each other, or by dividing the coils into sections and placing the sections of the primary between those of the secondary. The volts drop ($I\,R$) in the two coils due to forcing the current through their resistances, will also cause some decrease in the secondary E. M. F. Neglecting these considerations, however, the transformer will be perfectly self-regulating and the ratio of transformation of voltage will be directly as the ratio of the number of turns in the two coils.

The losses in a transformer are the $I^2\,R$ loss in the primary and secondary coil, and the hysteresis and eddy current losses in the core. The latter are known as the *core* or *iron losses*, and the former as the *copper losses*. This lost energy all disappears as heat. The copper losses vary approximately as the square of the load, whereas the core losses are independent of the load. The fact that the core losses are always the same whether the transformer has a light or full load, makes it important that this loss should be reduced to the smallest amount. This is especially the case with transformers which are operated throughout the twenty-four hours. The capacity of the transformer is made nearly equal to the maximum load which it is likely to carry, and the transformer is fully loaded or nearly so for only a few hours in the evening. Hence, throughout the remaining hours, as the core loss is constant, the efficiency of the transformer will be low. Any reduction in the core loss, will therefore cause a corresponding increase in efficiency for all loads. The core losses are decreased by increasing the frequency, but high frequencies have the objection of causing great inductance in the circuit.



**2400 HORSE-POWER CROSS-COMPOUND McINTOSH-SEYMOUR ENGINES,**
**With 1500 Kw. Direct-Driven Two-Phase Generators. Speed, 116 Revolutions per Minute.**

The average efficiencies of transformers at full load ranges from about 93% for a 500 watt, to 97% for a 15 K. W. transformer. The copper loss usually varies from $1\frac{1}{2}$ to 3% or more.

Unless transformer cores are made of a good grade of iron and very carefully annealed, the core loss after the transformer has been used for some months will greatly increase. This is known as *aging* of transformer cores, and was present to a very large extent in transformers as at first constructed, the increase in core loss often amounting to 50% of its original value. The high efficiency of a transformer when first installed, may therefore be considerably less after prolonged use. The use of a higher quality of iron well annealed has now greatly reduced this ageing effect.

Transformer cores are now largely made in the forms shown in section in Figs. 28 and 29. The primary coils *P* are usually wound over the secondary coils *S* as shown. This arrangement reduces the magnetic leakage to a very small amount. The magnetic circuit,

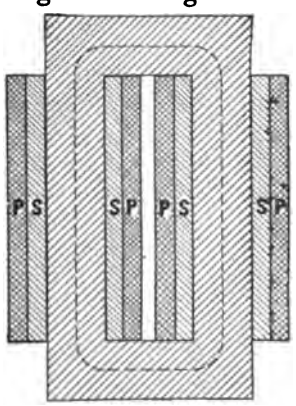



Fig. 28.

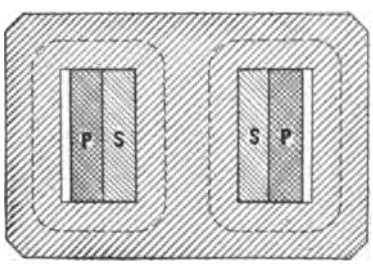



Fig. 29.

represented by dotted lines, is of a form which presents low reluctance. The number of joints in the core should be as small as possible in order to keep the reluctance low. It usually is not more than one or two.

The voltage of the primary is usually 1000 or 2000 volts, and the ratio of the turns such as to give a secondary voltage of about 100. Leads from two separate parts of the secondary coil are usually brought outside the transformer case, each half giving 50 volts. The halves may be connected in parallel and 50 volt lamps used, or connected in series for the use of 100 volt lamps.

## ALTERNATING CURRENT MOTORS.

**Synchronous Motors.** In order to operate an alternating current generator as a motor, it is necessary that its speed and phase should correspond with that of the generator supplying energy. Referring to Fig. 6, let us suppose the fields to be separately excited, creating poles as indicated, and suppose a single-phase alternating current to be supplied to the armature winding. If the speed of the armature is such that the reversals in direction of current occur just as the armature has moved the distance of one pole, there will be a constant torque exerted to continue the rotation; because when the direction of the current is reversed the windings have come under poles of opposite polarity, giving rotation in the same direction. If the armature is at rest, or not up to speed, the reversals of magnetism will occur before the armature has had time to move the distance of a field pole and no torque will then be exerted. Synchronous motors therefore have the disadvantage that they must first be brought up to speed by some additional device. After the machine has come into synchronism, its speed will correspond exactly with that of the generator for any change of load. The only method therefore of varying the speed of the motor is by varying the speed of the generator.

When no load is on the motor, its counter E. M. F. is in almost exact opposition to that of the generator. Only a slight current then passes through the armature and the torque exerted is small. On adding load, the motor will lag a few degrees, so that its counter E. M. F. will lag behind the applied E. M. F. The resultant pressure, which causes the current to flow in the motor armature, is equal to the difference of the corresponding instantaneous values of the applied and counter E. M. F. The greater the lag or phase difference between the two pressures the greater is the difference between their instantaneous values, and the greater the armature current. As the load increases the lag of the motor and the armature current become greater, and hence the torque increases directly as the load, since the torque exerted depends on the strength of the armature current. If however, too great a load is added, the torque, which the motor is capable of exerting, will be exceeded and the motor will fall out of synchronism and stop.

The advantage of applying the single-phase system to power purposes is of great importance. The fact however, that a synchronous motor requires some external machine to bring it up to synchronous speed, or else some self-starting device, has prevented their extensive application to general power distribution.

Small auxiliary motors are sometimes used to bring the single-phase motor up to speed with the load removed. The motor is then switched into synchronism, and the load added. The exciter of the motor is sometimes used to bring the machine up to synchronism. The exciter is then run as a direct current motor by a storage battery, the battery being recharged afterwards by the exciter after the alternator has been connected to its circuit. A small auxiliary series-wound machine is sometimes used. Such a machine is self-starting with an alternating current; it being series-wound, the fields and current in the armature will *both* reverse at the same time, and therefore the direction of the torque exerted will remain the same. Such motors can develop but small power owing to their excessive self-inductance. As the magnetism of the fields is constantly changing in such a motor, the fields must be well laminated to reduce eddy currents. A synchronous motor may be made self-starting by providing the armature with two sets of windings. Upon starting, the field and one of the armature windings which is provided with a commutator, are connected in series and the machine will start similar to the direct current series motor. The constant change in the direction of the current will make no difference. After its speed is attained, this auxiliary winding is connected to, and supplies a direct exciting current to the field coils, and the alternating current from the circuit is conducted to the main armature winding. The machine then operates as a self-exciting synchronous motor.

**Induction Motors.** These motors, also called rotary field motors, are usually run on two or three-phase circuits. They are self-starting, require no brushes or collecting devices, and operate at nearly constant speed. The currents from the line are usually supplied to a stationary winding, which causes the rotation of a core wound with a closed circuit of very low resistance. The stationary part is called the *stator*, and the revolving part of the machine, the *rotor*.

The motor is made to revolve by the action upon it of a rotating magnetic field. The production of this rotating field will be understood from Figs. 30 and 31. Fig. 30 represents the relations of two-phase currents which differ in phase by 90°. Fig. 31 represents the ring windings of the stator of an induction motor. The winding in this case consists of two independent circuits, supplied by two-phase currents. The curves $M$ and $L$ in Fig. 30 represent the currents supplied to the windings $M$ and $L$ respectively in Fig. 31. The different cases in the latter figure show the direction of the resultant magnetic flux for the different relations of the currents represented by the corresponding letters in Fig. 30. It is evident that at $A$ in Fig. 30, the curve $L$ has zero value and

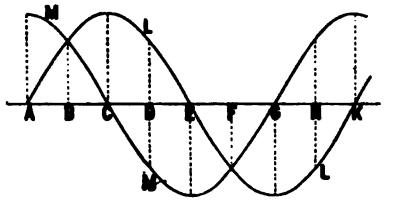


Fig. 30.

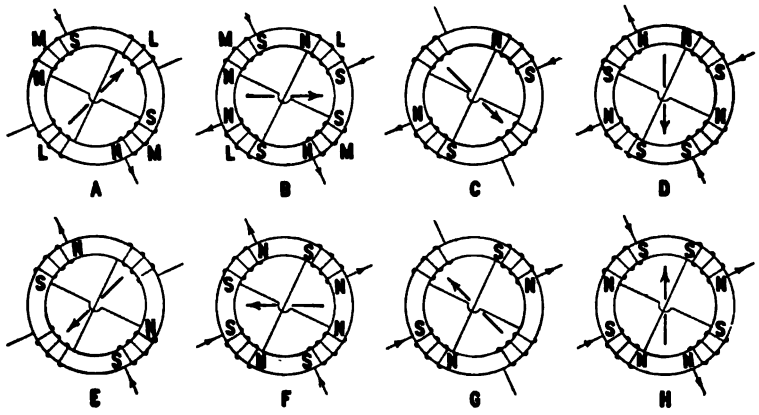


Fig. 31.

curve $M$ a maximum. Hence at $A$ in Fig. 31, there is no current in winding $L$ and a maximum in winding $M$. This current causes the production of poles $N$ and $S$ as shown, giving a resultant field across the ring, the direction of which is indicated by the arrow. At $B$ the current strength in each winding is the same and poles are produced as shown. The poles at the top and bottom of the ring neutralize each other, and there is a resultant field from left to right as indicated. At $C$, curve $M$ has zero value and curve

*L* a maximum, and the resultant direction of the magnetic field is shown at *C* in Fig. 31. At *D* the current strength is the same in each winding, but the current in winding *M* is opposite in direction to what it was in case *B*. This causes the direction of the resultant field to pass from top to bottom of the ring. The effect for the remaining cases of the complete cycle, is represented by *E*, *F*, *G* and *H*. It is evident from Fig. 31 that for one complete cycle, the direction of the resultant flux across the ring makes a complete revolution. Therefore, for currents having a frequency of 60, which is a common frequency for power distribution, the magnetic field will make 60 rotations per second. It may also be shown in a similar manner, that a rotating magnetic field is produced by the use of three-phase currents.

If a conducting mass of metal is supported within the ring, the constant rotation of the magnetic field about it, will cause eddy currents to be induced in the metal; because a varying magnetic field always induces eddy currents in conducting metals under its influence. We then have the condition of induced currents flowing in a closed circuit in the presence of a magnetic field. This is the essential condition of a motor, and therefore, if the metal is free to turn, the reaction of the induced currents upon the field will cause rotation. By confining the currents to paths which will prove the most effective in producing rotation, the efficiency of the machine may be made very high. The rotor is therefore, built up of laminated sheets of soft steel, and is wound with a closed circuit of large copper conductors. The induced currents are then confined to the copper conductors, which are at right angles to the magnetic lines, thus giving the greatest torque.

When the rotor is at rest, the rate of cutting the conductors by the rotating field is a maximum, and therefore the induced currents will then have a maximum strength. This would give a very large starting torque, were it not for the reaction of the rotor field upon that of the stator. The direction of rotation of the rotor is the same as that of the rotating field. Hence as the rotor increases its speed, the relative velocity between it and the field gradually decreases, as does also the rate of cutting the lines of force. The current gradually decreases, as well as the torque, until the motor assumes normal speed. The difference in speed between

the field and rotor is known as the *slip*. It is upon this difference in speed that the induced currents depend. The speed of the rotor may approach very closely that of the field but can never equal it. The less the resistance of the short circuited windings on the rotor, the less will be the slip necessary to induce the required current, and the higher will be the efficiency. Also when the load is increased, if the resistance of this winding is low, the increase in slip to produce the greater current required will be slight, and the fall in speed will be slight. Such a motor will therefore, run at nearly constant speed. In good rotary field motors of moderate size, the slip should not exceed 4%. Small motors may have a slip of 10%, and in very large motors it may be as low as 2%.

In motors having a bipolar field, such as we have considered in Fig. 31, the number of rotations of the field is equal to the frequency. It is desirable, however, that the speed of motors should be lower and therefore, they are made multipolar. If the stator is wound to produce eight poles, having alternate poles of opposite polarity, there will be four pairs of poles. If the frequency is sixty cycles per second, then the field will pass through only one-fourth of the circumference sixty times a second, and through a complete revolution one-fourth of sixty, or fifteen times a second. This will evidently reduce the speed of the rotor in the same proportion and obviate the use of gearing.

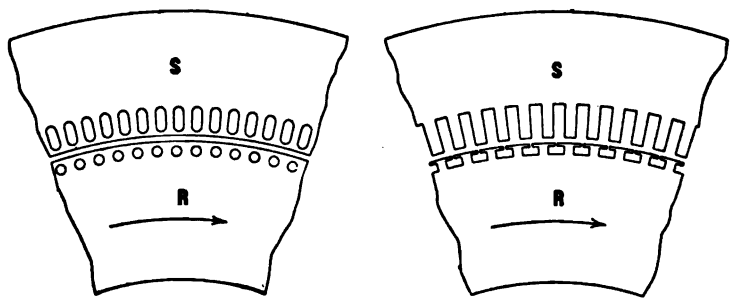



Fig. 32.

To avoid the production of eddy currents in the iron parts of the stator and rotor, they are built up of soft sheet-iron stampings. The windings are threaded through holes formed in the rotor and stator. Fig. 32 shows forms of the stampings in common use,

which reduce the reluctance of the magnetic circuit to a minimum. The stator is indicated by *S*, and the rotor by *R*.

The stator is usually drum-wound, and generally arranged to form eight or more poles. There is a large variety of rotor windings, the most common being what is known as the *squirrel-cage winding*. This consists of bars of copper, one placed in each slot and parallel to each other. Copper rings at the ends, join all the bars together, forming a short-circuited winding and having the appearance of a cage.

In starting an induction motor, the relative velocity between the field and the rotor is large, which causes excessive currents to be induced in the rotor. This is not only injurious to the machine, but considerably lowers the starting torque, due to the large reaction and distortion of the field. It is important therefore, that there should be some arrangement for reducing the starting current. Very small motors are not usually supplied with any starting devices, but for large machines they are necessary. A common method is the insertion of resistance in the rotor winding, causing the strength of induced currents to be reduced to any desired extent. The resistance should be gradually cut out as the motor gains its speed. This resistance may be carried by the rotor itself and connected into the winding. An arrangement is then necessary to gradually short circuit this extra resistance. The winding is sometimes arranged so that leads from it are joined to collecting rings on the shaft, and adjustable external resistances connected to the rings by brushes; the resistances are by this means inserted in the windings. Another method has the rotor coils connected in series on starting to give a comparatively high resistance, and connected in parallel while running to give low resistance.

If the E. M. F. applied to the motor upon starting is reduced, the effect will be to decrease the strength of induced currents, as in the case of inserting resistance in the rotor winding. If resistances are inserted in the circuits leading to the stator winding, the volts lost in the resistances will cause the E. M. F. applied to the winding to be much less. This method is similar to that used in direct current motors. Another method of reducing the E. M. F. applied to the motor, is by connecting a choke coil across the sup-

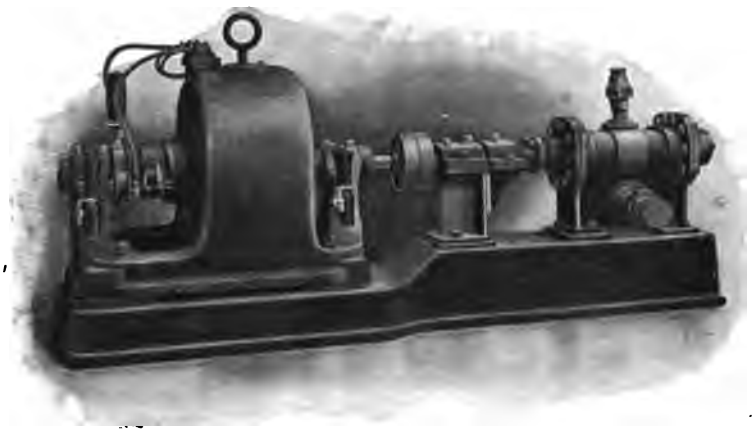
ply circuits. There will be a gradual fall of E. M. F. through this coil, and therefore any potential difference desired can be applied to the stator winding by connecting it to intermediate points along the choke coil. Reducing the applied E. M. F. is a very convenient method of starting a motor, but the starting torque obtained is considerably less than is the case when resistances are inserted in the rotor winding.

Induction motors can also be operated by means of a single-phase or simple alternating current supplied to a single stator winding. The magnetism due to this exciting current will rise and fall in strength and reverse in direction, but the field will not be a rotating one. If the rotor is at rest, currents will be induced in the winding but there will be no tendency to rotate, as the influence of one pole to produce rotation in one direction will be balanced by the influence of an opposite pole to produce rotation in the opposite direction. If, however, the rotor is given a certain speed, the effect of the magnetic field will be unbalanced, and the rotor will tend to keep up its motion. It will then run as a non-synchronous induction motor.

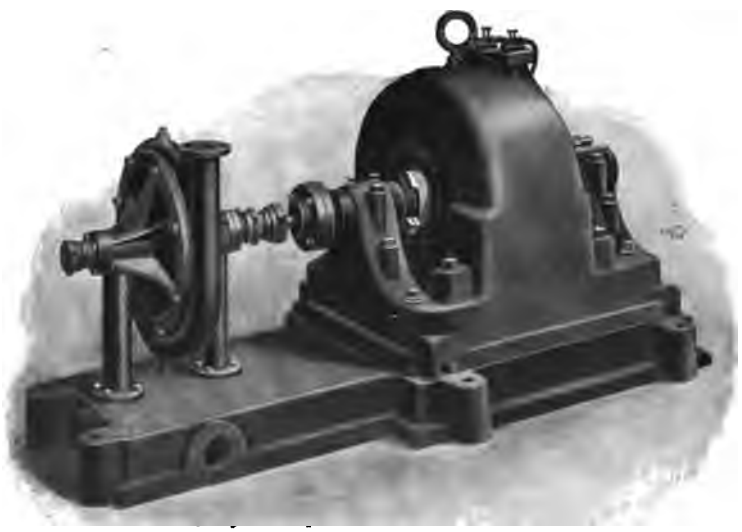
Such motors may be made self-starting by operating them as series motors while starting, as in the case of synchronous motors, or by the use of what is known as a *phase splitter*. The stator is then provided with two independent windings as in the case of a two-phase induction motor. In the circuit of one winding is connected a choke coil while a non-inductive resistance is connected in the other. The two windings are then connected in parallel to the supply circuit. One-half of the current will pass through each winding. The large self-induction of the choke coil will cause an excessive lag of current in the stator winding with which it is connected, and will consequently be out of phase with the current in the other stator winding. The single-phase current is by this means divided into two-phase currents. The motor will then be self-starting as in the case of a two-phase motor. After normal speed has been attained, one winding is cut out, or the two windings are connected directly to the supply circuit.

## MEASUREMENT OF POWER.

The power of a circuit carrying a simple alternating current is measured by means of a non-inductive wattmeter. In measur



**Direct-Current Wagner Motor, Direct Connected to Rotary Pump.**



**Single Phase Self-Starting A. C. Wagner Motor, Direct Connected to Centrifugal House Pump.**

ing power in two and three-phase systems the same method is adopted, but special arrangements may be made to reduce the number of instruments required and also the number of readings.

The method adopted in measuring the power of a two-phase system depends upon whether four wires are used, there being two independent circuits, or whether three wires are used, one serving as a common return or supply wire. In the former case the power is measured in the two separate circuits by the use of two wattmeters, one being connected into each circuit. The sum of the wattmeter readings, which should be made simultaneously, will give the total power of the system. If the system is balanced, that is, just as much power supplied in one circuit as in the other, then the total power will be twice the reading of one wattmeter. A balanced system is not usually secured in practice. If but one wattmeter is at hand, the power may be obtained approximately by inserting the wattmeter successively in the two circuits, and taking the sum of the readings. This would give the true power if the load did not change between readings.

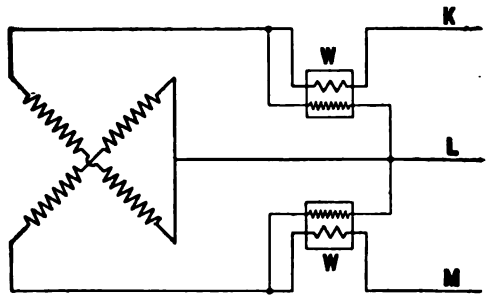



Fig. 33.

Where three wires are used, one wire being common, the arrangement shown in Fig. 33 gives the best results. The wires *K*, *L*, *M* correspond with similar wires in Fig. 23. Two wattmeters *W W*, are used, the current coil of each being connected in the outside wires, while the potential wires are connected across from the outside wires to the common wire. The sum of the wattmeter readings gives the total power. If the system is balanced, one wattmeter may be used. The current coil is then connected in the common wire as shown in Fig. 34. After a

reading is taken with the pressure coil connected to one outside wire, this connection is changed to the other outside wire, as indicated by the dotted line. The reading then obtained is added to the first reading to give the total power. If this method is

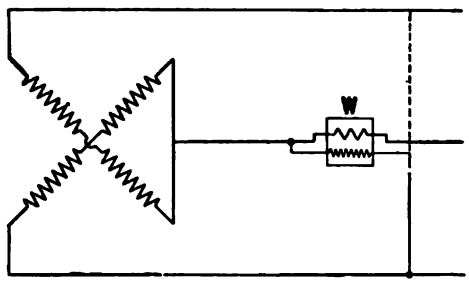



Fig. 34.

used, the system should not only be balanced, but no change in the load should occur between the two readings.

The power of a three-phase system may be measured by the use of three, two or one wattmeter. In the latter case however, the system must be balanced. Referring to Fig. 25, it is evident that the power of a machine having a star connected winding, may be obtained by inserting the current coils of three wattmeters in the three wires, and connecting the pressure coils about the windings *a*, *b* and *c*. Each wattmeter will then indicate the power of each branch, and the sum of the readings will be the total power. In the mesh connection the current coil of each wattmeter may be connected in circuit with windings *a*, *b* and *c* of Fig. 26, and the pressure coils connected about the windings from *A* to *B*, *B* to *C* and *C* to *A*. The sum of the three wattmeter readings gives the total power. If the system is balanced, three times the reading of one wattmeter gives the power.

Two wattmeters connected as shown in Fig. 35, may be used to measure the power in a three-phase system. The sum of the readings gives the total power if the power factor is greater than .5; if however, the power factor is less than .5 the difference of the two readings gives the total power of the system. An induction motor running on a light load will have a low power factor, but when fully loaded this may be from .7 to .9 or more. If it is not known whether the power factor is above or below .5, the

wattmeters may be interchanged without altering the relative connections of the current and pressure coils. If the deflections of both needles are then reversed, the power of the system is represented by the difference of the original readings. If the deflec-

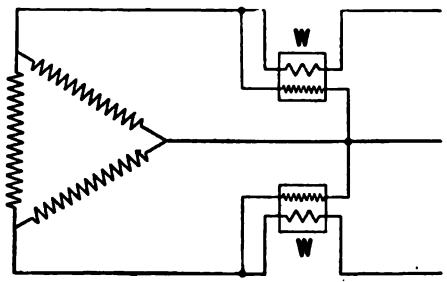



Fig. 35.

tions are in the same direction as before, the sum of the readings gives the power.

One wattmeter may be used if the system is balanced, and the load is fairly constant. The current coil is inserted in the circuit of one wire, and the pressure coil connected successively from that wire to each of the other two. The power is given by the sum of the readings taken for each connection.

NOTE. In the following pages — numbers 44 to 64 — will be found a brief description of the representative types of alternating current machinery as manufactured in the United States.

Direct current apparatus has been used for many years and types of such machinery are very numerous, but only within very recent years has the alternating current been used for general purposes, and therefore there are as yet but few standard types of alternating current machinery. We shall, however, give illustrations of some of the more prominent alternating current apparatus as made by representative American companies. These machines are described under three heads: — Alternating Current Generators; Alternating Current Motors, and Rotary Converters.

## TYPES OF ALTERNATING CURRENT MACHINERY.

The alternating current generator until within the last five years has been limited almost entirely to use in lighting circuits, as the older types of alternating current motors were unsatisfactory for general power service. It is true that the single-phase alternating current has long been used in a few unimportant cases for power—where motors were run without frequent starting and stopping; and even now small fan motors are run on single-phase alternating current lines. Still for large motors the single-phase alternating current has never been a success. Therefore, for nearly all circuits supplying electric power the direct current generator has been used.

Since 1896 the development of the synchronous and induction motors has brought about entirely changed conditions; the modern alternating current systems with the help of these motors have become entirely practicable for power distribution. In fact, since much higher voltages are allowable with alternating than with direct current apparatus, it follows that the alternating current system is generally speaking more efficient than the direct current method wherever electric energy has to be conveyed over long distances. This follows from the fact that for a given amount of electric energy, the higher the voltage used, the less will be the current needed, and hence the $I^2R$ losses will be proportionately less.

At present it is safe to say that the two systems, direct and alternating current, are equally prominent, with the tendency distinctly in the direction of alternating current work for future development.

Alternating current machinery is made by several of the leading electrical manufacturing companies in America and Europe, and the following pages contain examples of a few representative American types.

These machines are chiefly of the *two-phase* and *three-phase* types. The single-phase machine is not generally in use as it is not adapted to the requirements of either the synchronous or the induction motor. The two-phase generator ordinarily requires four transmission wires, two for each phase; the three-phase generator requires only three transmission wires, each of the

three transmission wires serving equally for two phases, so that three wires are thus made to take the place of six. The generator usually operates at moderately high voltages, its output being raised to the excessively high E. M. F. of twenty or thirty thousand volts or more by means of transformers. At this high voltage current is transmitted to the point at which it is to be used for driving machinery or for lighting. Here it is reduced in voltage by means of transformers to usually from one to five hundred volts, such E. M. F.'s being suitable for safe local use. At least one transformer winding is required for each phase at the generating end and a similar transformer winding at the motor end. A two-phase generator therefore calls for at least four transformer windings where a three-phase generator calls for at least six.

Alternating current generators may generally speaking be divided into (a) machines in which the armature revolves inside or outside of the stationary field; (b) machines in which the field rotates inside or outside of a fixed or stationary armature.

Fig. 36 shows one of the 1000 H. P. alternators manufactured by the **General Electric Company.** These generators are of the revolving field type. That is: to the engine shaft, shown broken in the illustration, is secured a large cast-iron spider, and to the circumference the pole pieces wound with the field coils are bolted. Current for the field coils is led in by means of two collector rings carried on the shaft. The armature windings are carried upon the inner face of the surrounding yoke or ring which corresponds exactly to the field ring of the direct current machines discussed in "Types of Dynamo-Electric Machinery (Direct Current)". The relative motion of field and armature is therefore exactly the same as if the armature were revolving inside a stationary field. The surrounding yoke is of cast iron, but carries on the inner face a laminated armature core corresponding to the laminated construction of standard direct current armatures. In this laminated core the armature coils are imbedded.

The General Electric Co. considers this arrangement superior to the revolving armature type for the following reasons: (1) The absence of moving contacts in the armature circuits; (2) The armature coils being stationary are much more effectively pro-

tected from injury than where the coils are revolving with great velocity; (3) This arrangement, by which the high potential armature conductors are concealed, gives a design that is much safer for the attendants; (4) The expense of elaborate, moving contacts for the armature is avoided.

Revolving field generators, like the one shown, are built for

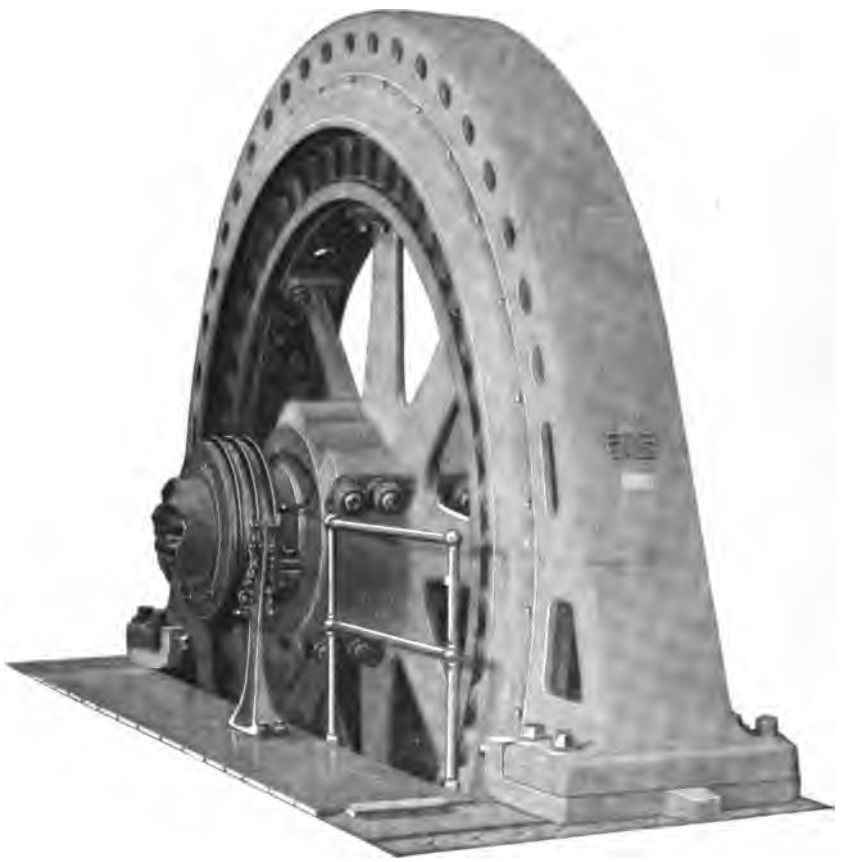


Fig. 36. 750 K. W. (1000 H. P.) General Electric Alternator with Revolving Field.

E. M. F.'s of from 240 to 12,000 volts. They are stated to give high efficiency and close regulation, and are wound for either two or three phase service.

The General Electric Company advocates the three-phase system, as the line losses are less than in the two-phase system,

and three wires are used in place of the four wires needed by the two-phase system.

Where the alternator is wound for an E. M. F. of not less than 10,000 volts it is usually practicable to transmit the current directly to the distant receiving station without the use of raising

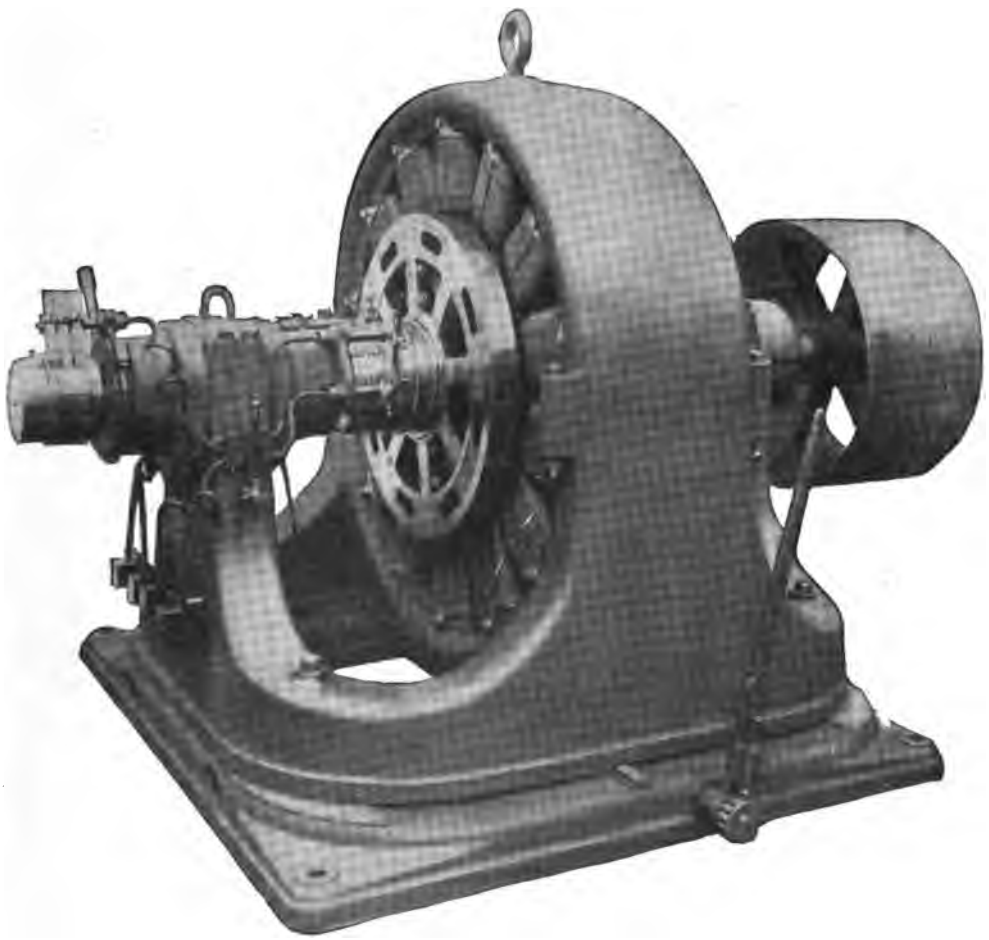


Fig. 37. Westinghouse Two-Phase Alternator.

transformers, thus doing away with the expense of these machines. However, in the majority of instances the alternator is wound for a comparatively low E. M. F. and raising transformers are used.

Fig. 37 shows a typical **Westinghouse** two-phase alternator or alternating current generator with an output of 180 K. W.,

with 7,200 alternations per minute. The lower half of the field, the base and the pedestals for the bearings, constitute a single casting. This casting having been accurately tooled, the exact centering of the armature is made certain. The pole pieces are of soft laminated steel cast into the field yoke. The bearings are so designed that they adjust themselves to slight unevenness of wear and remain continually in alignment.

The general construction of the Westinghouse alternator suggests strongly the uniform characteristics of Westinghouse direct current apparatus described in "Types of Dynamo-Electric Machinery (Direct Current)". For instance, the armature core is built up of soft steel and the armature coils lie in slots upon the face of the armature, being held in place by hard fibre wedges.

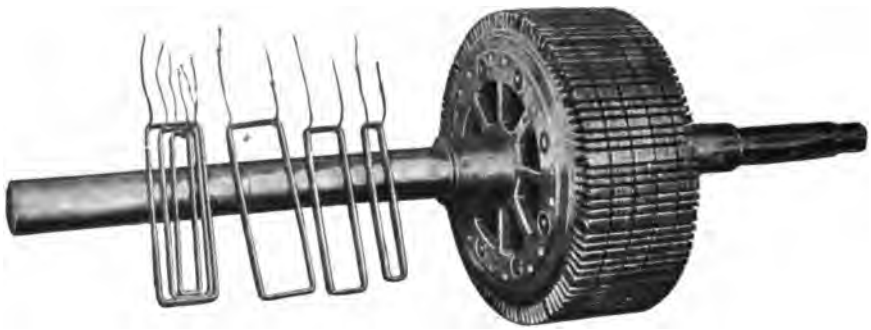
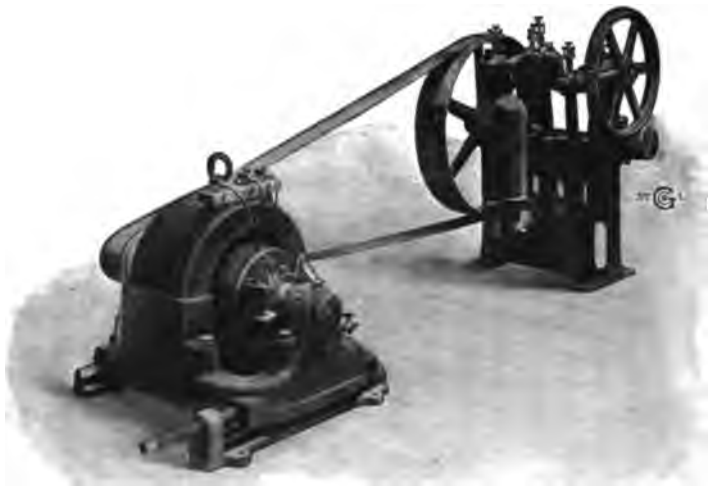
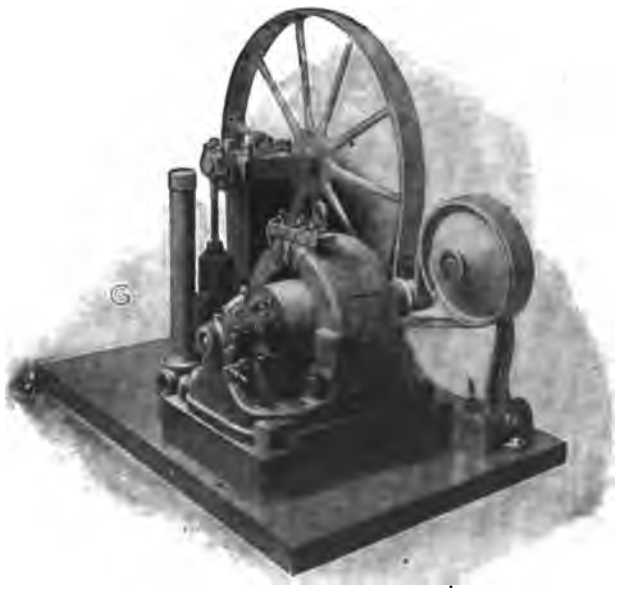


Fig. 38. Armature Core of Small Westinghouse Alternator.

These machines run at moderate speeds—from 325 to 900 R. P. M.—the field is usually excited chiefly from a small separate direct current machine used as an exciter, but in addition to the separate excitation the field has in the smaller sizes an auxiliary winding derived by commutation from the main armature windings and proportional in strength to the armature current. The commutator, by means of which this auxiliary field current is tapped off, is seen at the extreme left-hand end of the armature shaft in Fig. 37.

The Westinghouse E. & M. Co. makes machines almost identical in design with the one shown, built for single-phase use. They operate at 7,200 and 16,000 alternations per minute. These machines embody the general features of design that characterize the Westinghouse polyphase machines.





**Single-Phase Self-Starting A. C. Wagner Motors Belted to Pumps.**

The armature core for the single-phase machine is seen in Fig. 38 together with a few loose armature coils. The slots for the armature coils are clearly seen upon the core-surface, as are also the numerous air ducts which are left in the body of the core for ventilation. Armature ventilation is more thoroughly discussed in "Types of Dynamo-Electric Machinery (Direct Current)." It is sufficient to say here that the spider upon which

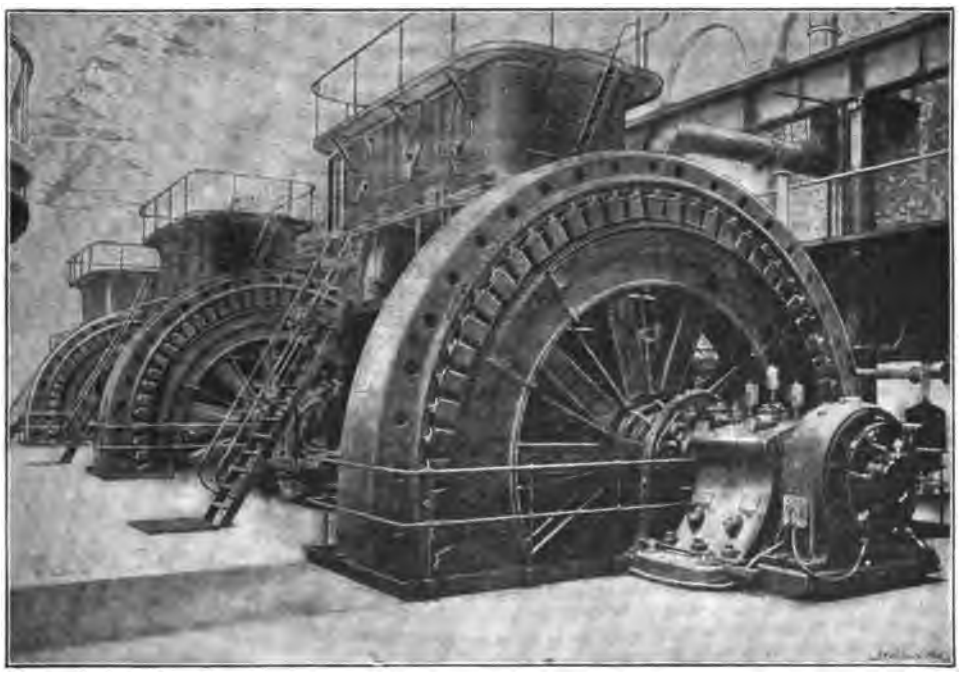


Fig. 39. Group of 1500 K. W. Westinghouse Alternators.

the armature core is built up is hollow, its interior being open to the free circulation of air. When the armature is rotating, currents of air drawn in through the spider are forced by the fan action of the armature through these ventilating ducts, thus keeping a constant blast of cool air in action through the armature windings. This principle of ventilation is characteristic of all high-grade modern dynamo-electric machines and no piece of electric apparatus should be installed for continuous running in which suitable provision for such ventilation is not made.

Fig. 39 shows a group of 1500 K. W. (2000 H. P.) Westinghouse alternators direct connected to vertical steam engines. Reasons for giving the preference to direct connected generators have been already outlined. Briefly, these are as follows: economy of floor space; avoidance of the losses introduced by belting; steadiness of running.

In the case of alternators, where the frequency of the alternations is directly dependent on the speed, the method of driving is determined chiefly by the size of the alternator and the kind and speed of the prime mover. Machines in sizes below 100 K. W. are belted; sizes above 200 K. W. are preferably direct-coupled to the driving power. Since the frequency is proportional to the number of poles, it follows that for a given frequency a slow-speed alternator will have more poles than one designed for higher speed. Its weight and cost will also be greater.

Fig. 40 shows the core for a rotating armature partially built. The heavy cast-iron spider is laid upon its side and the punched sheets of steel which are to form the armature core are laid in place surrounding the spider and keyed to it by means of dove-tailing projections which fit into corresponding recesses in the face of the spider.

Fig. 41 shows on a large scale a small portion of the windings of a rotating alternating current armature. The windings,

Fig. 40. Partially Built-up Core of Rotating Westinghouse Armature.

which are massive copper bars separately insulated, are seen in position sunk within the slots upon the face of the core and bolted to end connectors.

It must be obvious that since the current generated results from the mutual or relative motion of field and armature it makes

no difference in theory whether it is the armature that rotates or the field. In the rotating field generators the windings shown in Fig. 41 instead of being spaced around the circumference of the

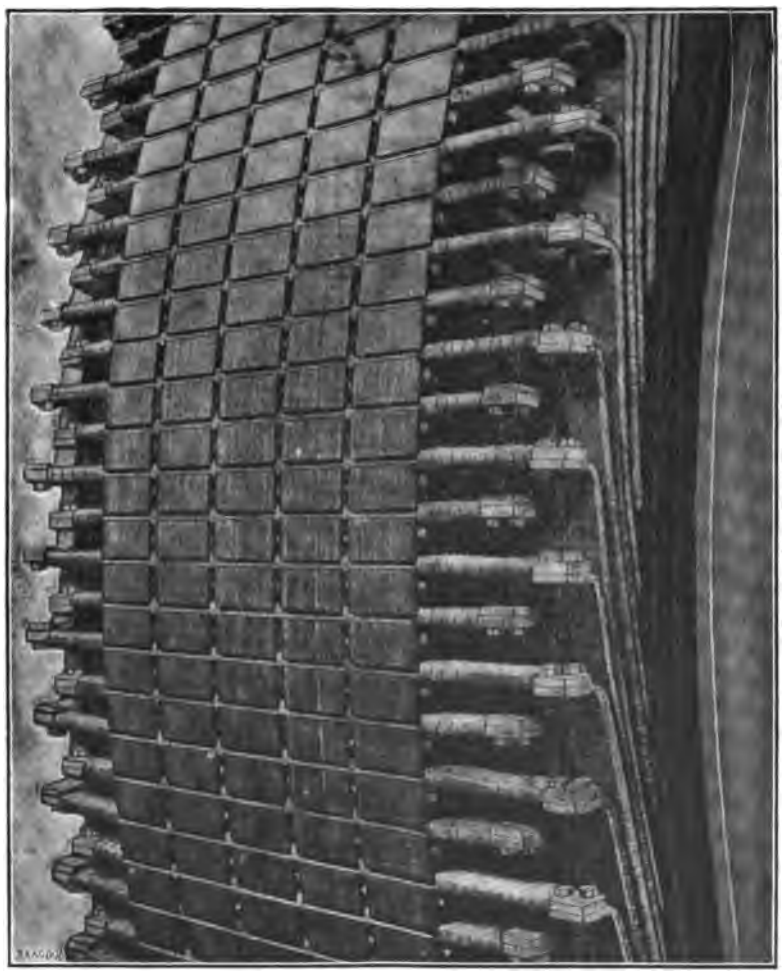


Fig. 41. Detail of Westinghouse Armature Windings. (Rotating Armature.)

rotating part are spaced upon the inner face of a stationary ring surrounding a rotating field. Such an arrangement by way of contrast is shown in Fig. 42.

## ALTERNATING CURRENT MOTORS.

As already explained, modern alternating current motors are chiefly of two types, synchronous and induction. The synchronous motor shows a high efficiency and takes very heavy overloads without losing its synchronism. The synchronous motor however does not give a powerful starting torque, and for service where such a torque is necessary it is usual to employ the induction motor.

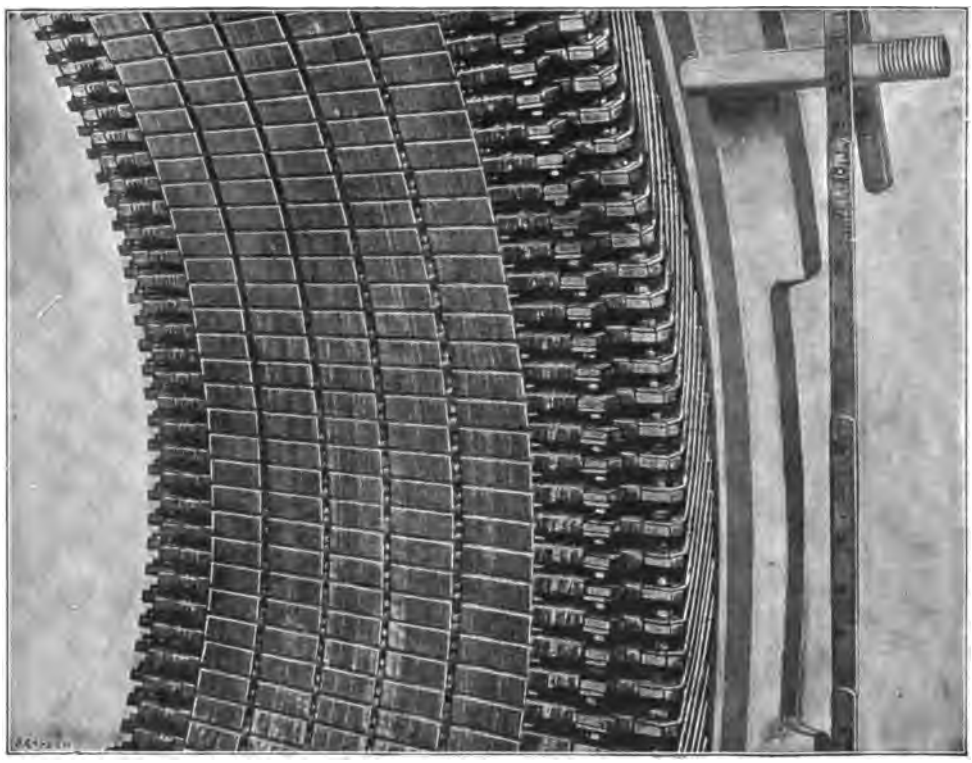


Fig. 42. Detail of Westinghouse Armature Windings. (Stationary Armature.)

The chief advantage of this motor lies in its great mechanical strength. Its armature usually carries bare copper conductors of massive design; there are no moving contacts, brushes or commutator segments, so that the revolving part of the motor is practically indestructible. Induction motors run with practically no attention, – hardly more than that needed by a shaft hanger, – and they may be bolted upon wall or ceiling in any desired posi-

tion. As there are no delicate armature conductors or contacts, nothing need be feared from dust or dirt. Provided the field coils are not burned out by an excessively heavy inrush of current no electrical injury is to be feared for the motor.

Fig. 43 shows the **General Electric** 1000 H. P. revolving-field synchronous motor. Geared to the shaft of the motor will

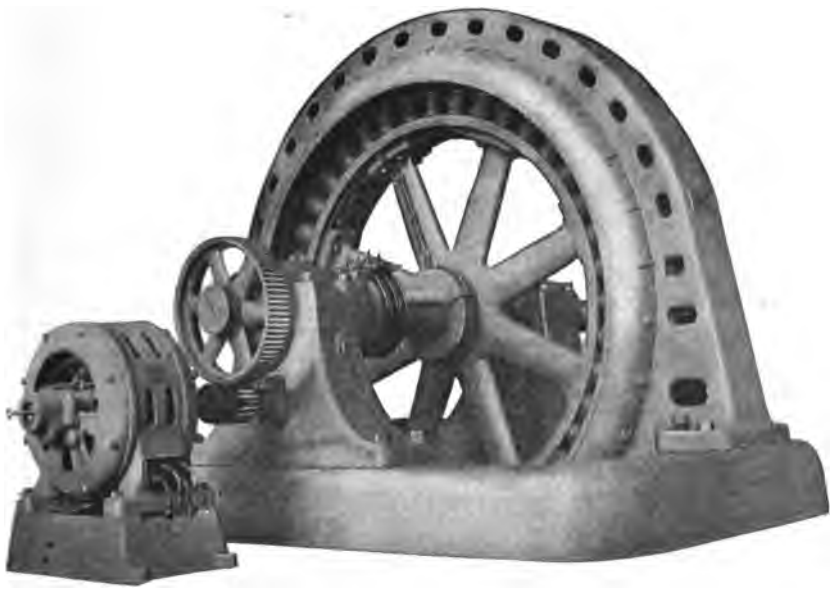


**Fig. 43. 1000 H. P. General Electric Synchronous Motor with Revolving Field.**

be seen a small starting motor for bringing the large machine quickly up to speed. A motor of this size would ordinarily be connected direct to the shaft of the machinery which it drives. Fig. 44 shows a General Electric 40 H. P. induction motor. This latter machine is "iron-clad" and although its rotating part is of very strong construction and not subject to breakdowns the exterior casing gives abundant protection to the interior. In the armature of this motor is fixed a starting resistance which may be gradually cut out by means of a convenient switch handle. With-

out this starting resistance an excessive current would flow while the motor was getting up speed. The General Electric Company makes motors of this general design up to 1200 H. P. capacity.

Fig. 45 shows a 500 H. P. **Westinghouse** induction motor. Fig. 46 shows the "secondary" or rotating part of such a motor, and Fig. 47 shows the "primary" or stationary portion of the motor. The rotating portion is built up of laminated steel discs

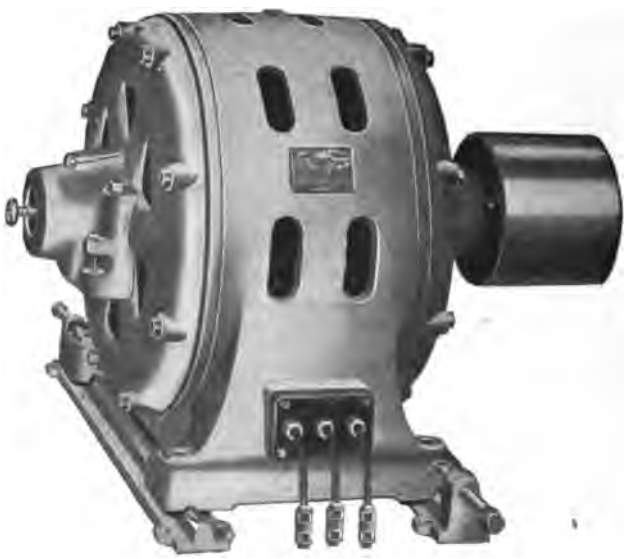


**Fig. 44. General Electric 40 H. P. Induction Motor.**

mounted upon a spider and is "wound" with heavy copper bars sunk in slots. The current flowing in these conductors is induced by the currents in the surrounding field, and although very large in quantity is of extremely low E. M. F. The copper conductors therefore require far less insulation than direct current motors for high E. M. F. service. In fact all the armature conductors are permanently short circuited at each end, being bolted directly to metallic rings which surround the armature. No accidental short

circuit can therefore affect the armature in the slightest degree and the construction is practically indestructible. The primary or stationary portion of the machine has a similar core of laminated steel and the insulated field windings are sunk in slots in this

Fig. 45. 500 H. P. Westinghouse Induction Motor.

laminated core. Surrounding the field windings is a strong cast-iron yoke holding the primary rigidly in position and forming the supporting frame-work of the machine.

Fig. 46. Secondary or "Rotor" of Westinghouse Induction Motor

Fig. 47. Primary or "Stator" of Westinghouse Induction Motor.

## ROTARY CONVERTERS.

In "Types of Dynamo Electric Machinery (Direct Current)" we discussed motor generators and dynamotors. We

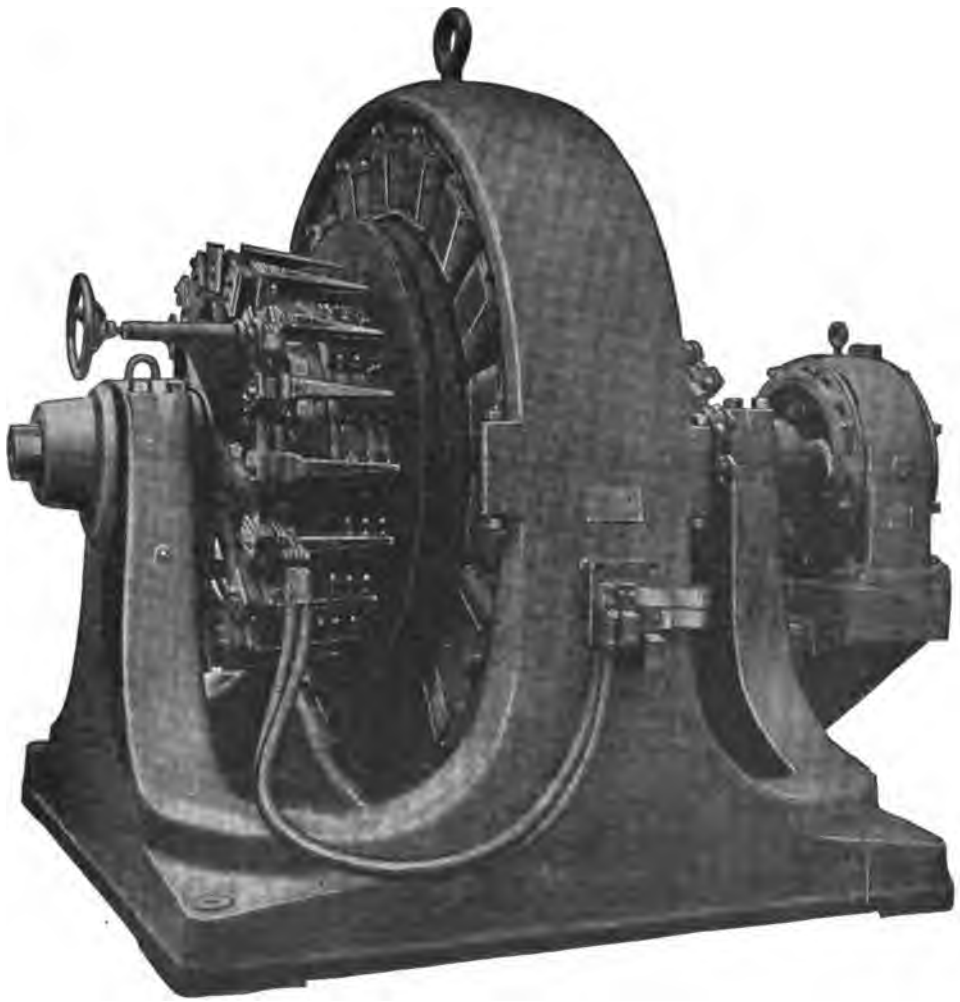


Fig. 48. 500 K. W. Westinghouse Rotary Converter.

saw that the function of these machines was to give out a current of a given voltage when supplied with a current of different E. M. F. In the same general class with the dynamotor should be

included the "**rotary converter,**" in which an alternating current motor is combined with a direct current generator, the machine having only one field and one armature.

For transmitting electric power over considerable distances the alternating current possesses important advantages which we have already discussed. Accordingly the alternating current system is employed at Niagara, Snoqualmie Falls and a great number of smaller water-power plants. Nevertheless there are many plants and processes which require a direct current supply. Such for instance is the Buffalo street railway system, which obtains its power from the Niagara Falls plant. At that plant the alternating current generators, driven by huge water turbines, give out an alternating current of moderately high E. M. F. By means of transformers this is raised to a very high E. M. F., at which the current is sent overland to Buffalo. At Buffalo the alternating current (brought down to a moderate E. M. F. by means of transformers) is supplied to rotary converters. These converters give out a direct current of about 500 volts, suitable for use on trolley lines. Cases of this sort are now very common and for such service the rotary converter has become indispensable.

A typical rotary converter is shown in Fig. 48, giving a view of the **Westinghouse** 500 K. W. rotary converter with starting motor. This machine consists of an alternating current motor, the current for which is supplied through the collecting rings at the right of the shaft. The special peculiarity of this machine and similar rotary converters is that the armature winding that forms part of the motor circuit also does duty as the armature winding of the generator part. That is to say, the armature winding, acting as part of the alternating current motor and of course carrying an alternating current, is tapped at regular intervals of distance around the armature by copper lugs, connected to the segments of a commutator. An extended description of the armature winding does not belong in this place, but it should be remembered that the current induced in any direct current generator is alternating, and is only made direct by means of the commutator. An alternating current is induced in the windings of the converter armature operating as a motor, and by leading out these induced currents to a suitable commutator a

direct current output is obtained. There will be of course a fixed ratio between the E.M.F. supplied by the alternating circuit to the converter, and the direct current E.M.F. given out from the commutator of the machine. For this reason, as a direct E.M.F. of fairly low figure is required in the direct current service, the converter has to be supplied with an alternating current of cor-

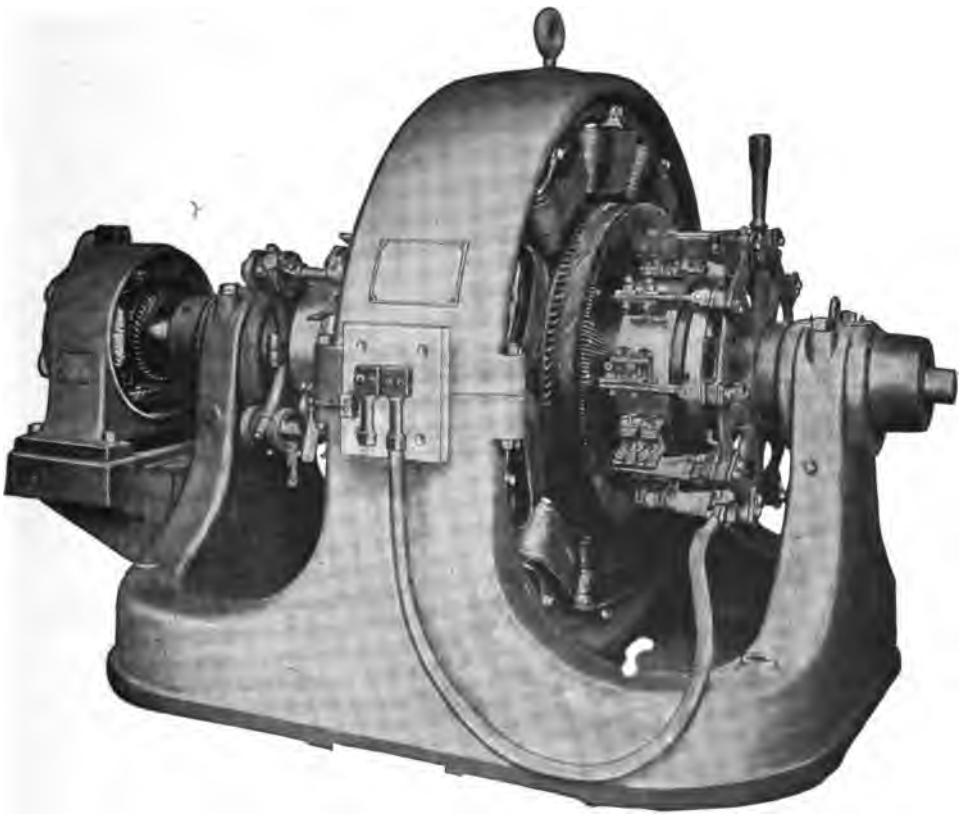


Fig. 49. Westinghouse Rotary Converter for Converting Direct Current into Alternating Current.

respondingly low E.M.F. This E.M.F. is obtained by means of transformers.

It should be borne in mind that the rotary converter merely takes the place of an alternating current motor driving a separate direct current generator. The converter however gives

much better results for the reason that the friction of the motor and the connecting gear between it and the generator are entirely eliminated, one set of bearings being all that is necessary. Also the combination of the motor and generator in one armature winding gives a machine of very compact design.

A rotary converter is operated like a direct current generator while running, but as it is operated by an alternating current it is not usually self-starting. Accordingly some method of starting the rotary converter is provided in the station. If there is a direct current supply of electricity available, the converter may be started by connecting it to the direct current supply. It will then act as a direct current motor. Otherwise it may be started by means of a small motor operated from the alternating current, and either belted to the converter shaft or directly coupled to it. The alternating current motor used for this service is of the "induction" type, which is self-starting when no load is connected to it. In Fig. 48, showing a 500 K. W. Westinghouse rotary converter, it will be seen that at the right end of the shaft is fixed a small motor, by means of which the converter is started, this machine not being self-starting. Fig. 49 shows a similar machine, which, however, is primarily designed to have the motor side direct current, while the generator side gives out an alternating current. Machines of this class are much less common than those in which an alternating current is changed into a direct current supply. The Westinghouse Company manufactures rotary converters in a great variety of sizes, from 2 K. W. capacity, operating at 1800 R. P. M., up to 1500 K. W. capacity, running at 250 R. P. M. The machines are designed for E. M. F.'s ranging from 125 to 650 volts.

Reference has been made to the Niagara Falls power plant. The alternating current generators in this installation are of the Westinghouse make. Fifty thousand H. P. of electric supply is sent out from this point to factories and mills situated in the surrounding country. The value and importance of the rotary converter are shown by the fact that a large part of this 50,000 H. P. is sent through rotary converters and transformed into continuous current.

Fig. 50 shows a number of **Westinghouse** rotary converters installed at the San Gabriel Electric Company's plant near Los Angeles, Cal. One of these machines is of 400 K. W. capacity; the other three are of 250 K. W. each.

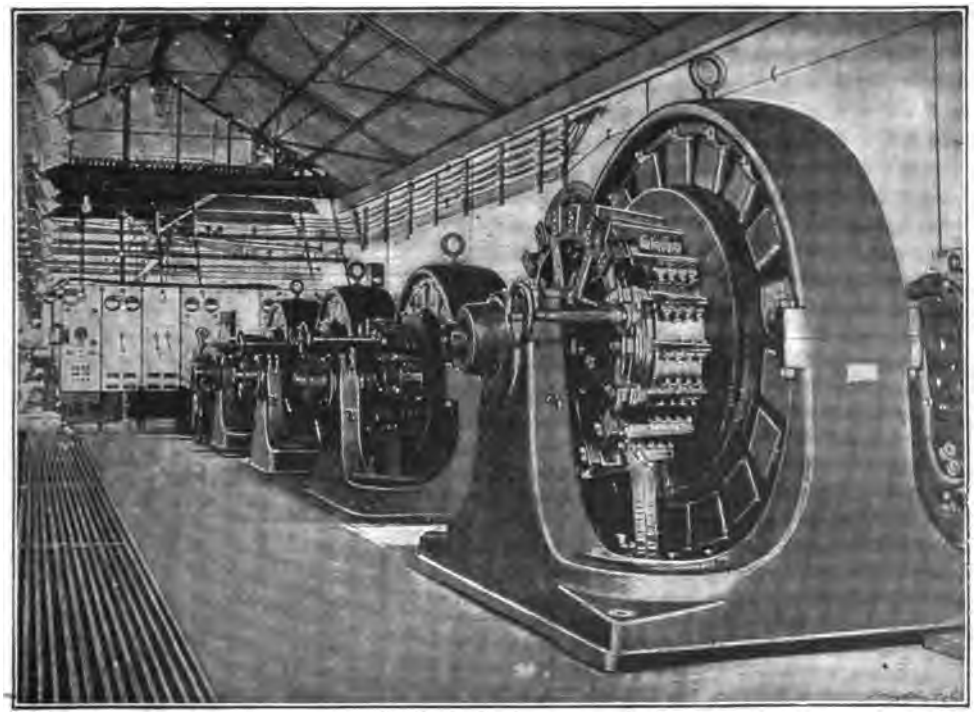


Fig. 50. Group of Westinghouse Rotary Converters.

The advantages of the alternating current method are so clearly understood today that in nearly all the recently equipped central power stations alternating current apparatus is in use. Also in re-equipping older plants provision is in many instances made for changing over the system at some future time to the alternating current. Fig. 51 shows a machine intended for use in such a remodelled station. It is a rotary converter supplied with a driving pulley, seen at the right hand end of the illustration. For the present such a machine is intended to be driven by a steam engine and to operate as a direct current generator, the alternating side of the machine being

ignored. At a later date when the plant is changed over to the alternating current system this machine will be disconnected from the engine, removed to a distant point and driven as an alternating current motor supplied from the central station, and it will then give out a direct current for local use. The prominent street railway companies of New York City are already using rotary converters and the Manhattan Elevated Railway is being adapted for their use.

The rotary converter is, as will readily be seen, very flexible

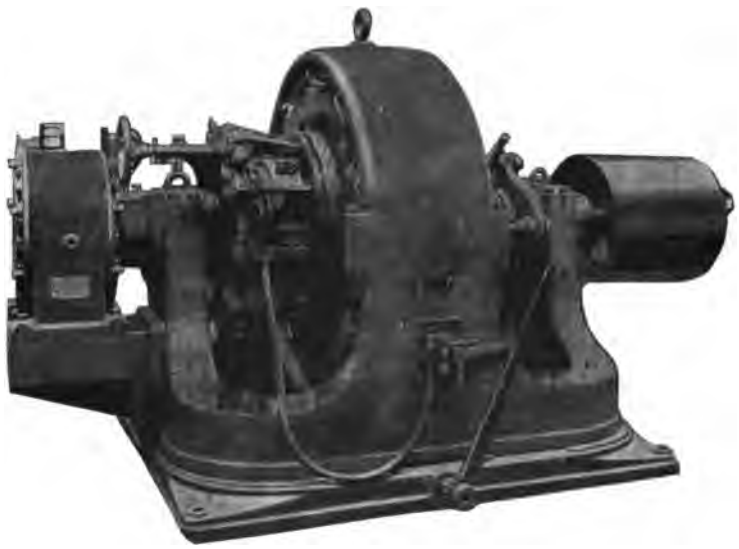


Fig. 51. Westinghouse Rotary Converter for use as a Belt-Driven Generator.

in operation. It may be driven by a steam engine or other source of mechanical power, and connected to give out either direct or alternating current; or it may be so driven and connected to give out both direct and alternating currents. It may be driven as a direct current motor supplied from direct current mains, and giving out mechanical power by means of a pulley fixed on its shaft while at the same time an alternating current is given out from the collector rings. Or it may be connected to an alternating supply and arranged to give out mechanical power from its

pulley while at the same time delivering continuous current from its commutator. Or it may be supplied with alternating current, giving out only direct current; or else supplied with direct current, giving out only alternating current. Or it may be driven as a direct or alternating current motor, from direct or alternating current mains respectively.

**The General Electric Company** is now manufacturing rotary converters which are capable of being started from the alternating current supply without any special or separate starting device.

These machines have the following general features of design. The external yoke of the frame is made of cast iron, the upper half being fastened on by means of hidden bolts. The poles are castings of solid steel bolted into the yoke, and each pole may be removed separately for repairs. The lower half of the yoke is cast separately from the bedplate, so that the entire field ring or yoke may be moved sideways along the bedplate, if it is desired to examine the armature windings. Also the field yoke and the bearing pedestals may be moved laterally or shimmed up in order to adjust the armature concentrically with the pole pieces. The poles have extending tips, by which means the magnetism is distributed more uniformly and the iron losses reduced. The field coils are either shunt or compound wound, with adjustments precisely like those used on direct current generators. The armature is well ventilated, radial air ducts giving a continuous blast of air throughout the armature. The armature in fact acts like a centrifugal fan. The armature is ordinarily bar wound, and the windings are held in slots by means of wooden wedges. The commutator is like that used on the General Electric direct current generators. The collector rings for the alternating current side of the armature are separated from one another by air spaces, giving good insulation. Carbon brushes are used in brush holders of the standard type on the direct current commutator, while laminated copper-leaf brushes are used on the collector rings.

The wear on the commutator and collector rings is rendered uniform by means of an automatic device known as an oscillator, which at regular intervals shifts the armature slightly back and forth along the line of the shaft.

The General Electric rotary converters in sizes up to 1000 K. W. are used in a great number of street railways as well as "interurban" lines connecting neighboring cities. Such for instance are the lines between Buffalo and Lockport, Chicago and Milwaukee, Philadelphia and West Chester, and the railway lines in Paris, London, New York, Albany, Chicago and St. Louis.

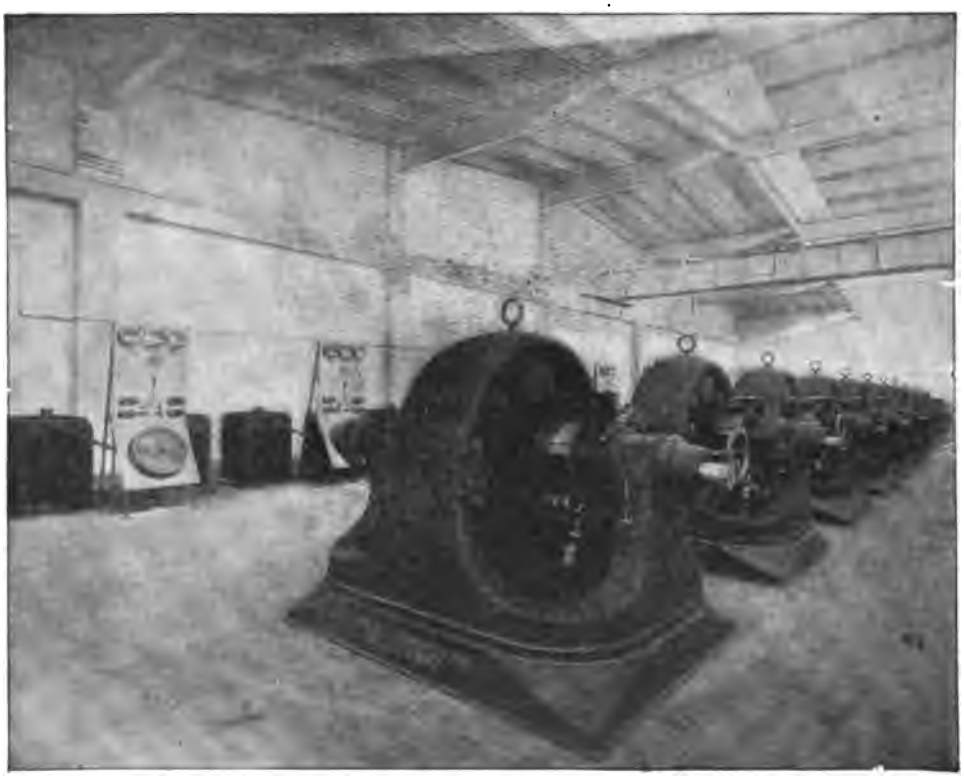


Fig. 52. Westinghouse Rotary Converters at Mathieson Alkali Works, Niagara Falls.

**Rotary Converters for Electrolytic Work.** For electrolytic work where only an alternating current source of supply is available the rotary converter is now extensively used. Fig. 52 shows a group of **Westinghouse** 126 K. W. rotary converters installed at the Mathieson Alkali Works, and supplied with alternating current from the great Niagara plant.

## SECTION 3.

# ELECTRIC LIGHTING.

The application of electricity to lighting purposes presents such great advantages over other methods, that its introduction within the last twenty or twenty-five years has been very extensive. The lighting of streets, highways, parks, mills, factories and every kind of building by means of electricity shows its importance and general application.

Electric lighting may be divided into two systems according to the kind of **lamps** used, that is, we have the incandescent and the arc lighting systems. We could also make a classification with reference to the **current** used, having the direct current and the alternating current. Further considerations would lead to a classification according as to whether the lamps were run on a constant **current** system or on a constant **potential** system.

In this work the different types of electric lamps will first be considered, then the systems of distribution of electrical energy to the lamps, being followed by the special requirements of the generating plant for electric lighting, the details of the overhead and underground systems, the details of wiring a building, and finally, methods of calculating the size of wire.

### MEASUREMENT OF CANDLE POWER.

**Candle Power.** In comparing lamps and in determining their efficiency, it is necessary to know their candle power, and before taking up the subject of electric lamps we shall first consider how this is measured.

The **candle power** of a light is the number of lights of unit intensity which would be required to equal its own intensity.

The **unit of light** commonly used is a spermaceti candle $\frac{1}{8}$ of an inch in diameter, so proportioned as to burn 120 grains per hour.

Six such candles weigh one pound. They are made tapering slightly, and it is customary to cut the candle into two parts at the centre, and to light the new ends, as they give a more uniform light burning in this way.

The unit adopted by the International Congress of Electricians at its meeting in Paris in 1884, is the light emitted by a square centimeter of melted platinum at the temperature of solidification. This unit is equal to 19.7 standard candles.

**Photometer.** A photometer is an instrument or apparatus which may be used to measure the candle power of a light. The principle of all photometers is to make the illumination produced on a given surface by two lights, vary in a continuous and determinate manner until equal. The one in general use is the **Bunsen.**

Figure 1 shows the arrangement of this photometer. *A* is the standard candle, and *B* the lamp whose candle power is to be

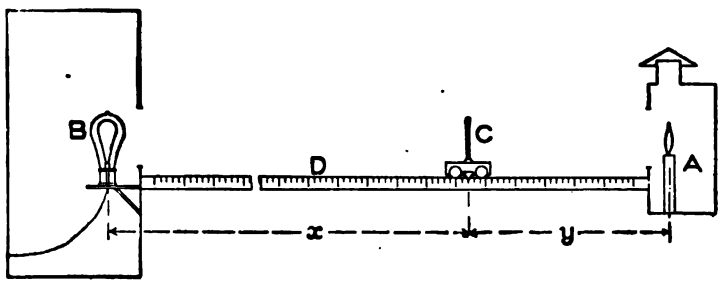



Fig. 1.

measured. The distance between these two lights is accurately graduated on the scale *D*, which may have a length of about 10 feet. *C* is a paper disk the central portion of which is transparent, this part being greased. *C* is movable along the scale, and has back of it two inclined mirrors so placed as to make both sides of the disk visible at once. The whole apparatus is in a room whose walls are black, and there is no other source of light besides the two mentioned.

To determine the candle power of *B*, the disk is moved to such a position on the scale that each side, as seen by the mirrors, is of equal brightness. That is, the disk at a distance $x$ from the lamp, and distance $y$ from the candle receives the same amount of illumination from one source as from the other.

Since the intensity of illumination received by an object varies inversely as the square of its distance from the source, we have the proportion,

$$c.\ p.\ of\ lamp : c.\ p.\ of\ candle = x^2 : y^2$$

$$\text{or,} \quad c.\ p.\ of\ lamp = \frac{x^2}{y^2} \times c.\ p.\ of\ candle$$

$$= \frac{x^2}{y^2}$$

if a standard candle is used.

Example.—In finding the candle power of an incandescent lamp, the disk showed equal illumination when at a distance of 2 feet from the standard candle and 8 feet from the lamp. What was its candle power?

Solution.—Here $x = 8$, and $y = 2$. By applying the formula we have,

$$c.\ p.\ of\ lamp = \frac{x^2}{y^2} = \frac{8 \times 8}{2 \times 2} = 16.$$

Ans. 16 c. p.

Lamps of large candle power are more accurately compared with a light of greater intensity than that of the standard candle.

Example.—In measuring the candle power of a lamp, equal illumination was obtained on both sides of the disk when it was 6.5 feet from this lamp, and 3.5 feet from a lamp taken as a standard whose candle power was known to be 16. What was the unknown candle power?

Solution.—In solving this example the ratio of the squares of the distances must be multiplied by 16 in order to reduce to standard candle power.

$$c.\ p.\ of\ lamp = \frac{6.5^2}{3.5^2} \times 16 = 55.18+$$

Ans. 55.18+ c. p.

The Bunsen photometer gives satisfactory results only when the two lights are of nearly or exactly the same color. When both sides of the disc are equally illuminated by lights of the same color, the grease spot becomes almost invisible; but if, for example, an arc light is measured against an incandescent lamp, no position of the disc can be found where the spot is not perfectly distinct and quite different in color from the ungreased paper. In this way two observers will often obtain widely different results from the same lamp.

Other forms of photometer have been devised to meet this difficulty, but none remove it entirely.

**Mean Spherical Candle Power.** Since the amount of light given off by a lamp in different directions varies greatly, this variation being greater for some lamps than for others, it is necessary for a fair comparison between lamps to determine their **mean spherical candle power,** that is, the average of measurements of the candle power made in every direction about the

lamp. In obtaining this, measurements are made with the lamp turned in different regular positions, and an average of all the resulting candle powers gives the mean spherical. For a good determination as many as thirty-eight different values must be averaged.

**The Mean Horizontal Candle Power** is also useful, this being the average of the values obtained when the lamp is turned through a regular number of degrees on its vertical axis only, giving the average illumination in a horizontal direction. An average of twelve values will give a fair determination.

## INCANDESCENT LAMPS.

**Principle.** We have learned in preceding work that one of the results of electricity passing in a conductor is to heat the conductor, and that the heating varies directly as the resistance and as the square of the current. Then by passing a current through a conductor of high enough resistance, it can be heated to incandescence, or white heat, so giving off light.

As carbon does not melt or volatilize at a high temperature, it has a great advantage over other substances for use in electric lamps. It does however oxidize, and it has been found that the only suitable manner of preventing this, is to enclose the carbon in a glass bulb from which the air has, as nearly as possible, been exhausted.

**The Filament.** Since a high resistance is necessary very thin threads or **filaments** of carbon are used. These are prepared from various organic substances; those commonly used being vegetable fibres, bamboo, silk, cotton thread, and cellulose which is mostly used at present, being a preparation of cotton, linen, wood pulp, paper, etc. Each manufacturer has special methods, but the general treatment of **cellulose** to form a filament is as follows:

After the cellulose is treated with sulphuric acid, converting it into what is known as vegetable parchment, it is forced through a series of dies gradually reducing its cross-section until a thread of the size desired is obtained. This thread is wound upon two bars, or moulds of carbon or porcelain in such a manner as to give them the shape they will have in the lamp. Several of these sets of bars are placed together in a crucible, all intervening space being

closely packed with powdered charcoal. The crucible is then hermetically sealed, placed in a suitable furnace, and raised slowly to a white heat. This treatment, known as **carbonizing**, renders the filament hard, durable, and increases its conductivity. After cutting, the filaments are **flashed** over with surface carbon by being heated electrically in an atmosphere of some hydro-carbon. This gives them a uniform diameter throughout, and the required resistance.

The candle power of the lamp varies according to the size and length of the filament; high voltage lamps require a long fine filament, while low voltage lamps have one which is short and coarse and carry a comparatively large current.

**The Lamp.** Fig. 2 shows a lamp of the Edison type, and every incandescent lamp has the same general characteristics. *B* represents the glass bulb and *F* the filament. This is mounted on two short wires *p*, which are made of platinum on account of its being infusible at a high temperature and expanding when heated in the same degree as glass. Each of these wires has connected with it a short copper wire *c*, one of which is connected to the brass contact piece *l*, and the other to the brass screw piece *k*. Plaster of Paris is used in fixing the bulb into the piece *k*, and this also insulates *l* from *k*. Before introduction into the bulb the platinum and copper wires are encased in a small glass tube, and are partly embedded as shown at *u*. To the free platinum ends is fixed the filament. The whole is then introduced into the glass bulb, and the tube united with it.

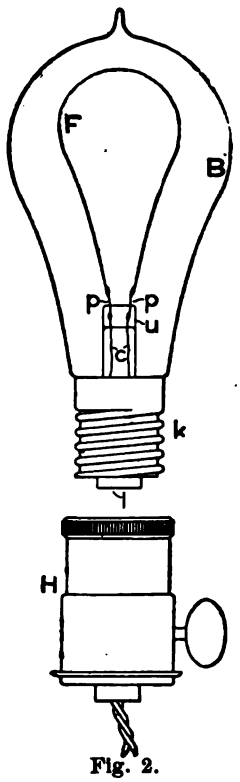


Fig. 2.

The lamp **holder** or **socket** is shown at *H*, and to this are connected the conductors supplying the current. When the lamp is screwed into its socket the filament is brought into the circuit as *l* comes in contact with a similar piece which has one of the conductors attached to it, the other contact being made between *k* and

the screw piece in *H* to which is attached the other conductor. Some holders are provided with a key or switch for making and breaking the lamp circuit, otherwise the lamps are controlled by an independent switch.

**Exhausting.** The lamp is exhausted through a small tube at the top of the bulb. This has to be done very carefully and presents the greatest difficulties. Since a high degree of exhaustion is necessary the mercurial pump is the only one that proves satisfactory.

The principle of one of these will be understood from Fig. 3.

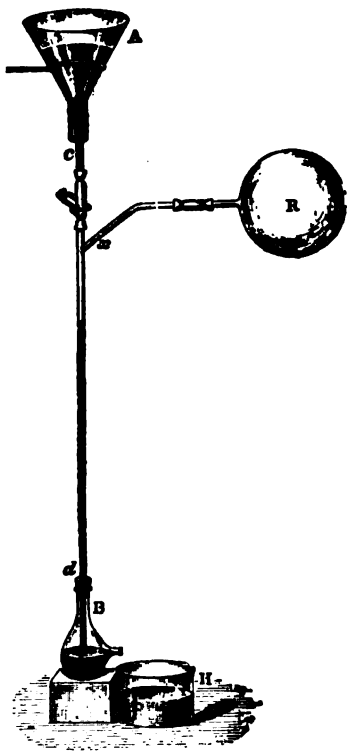


Fig. 3.

A large funnel-shaped reservoir *A*, containing mercury is connected with the glass tube *c d* by the rubber tube at *c*, this being opened or closed by a clamp. The tube *c d*, about 40 inches long, extends down into a flask *B*. This has an outlet, a little higher than the end of the tube, leading into the basin *H*. From the main tube extends a branch *x* provided with a rubber tube to which the globe to be exhausted, represented by *R*, is connected. By repeatedly opening and closing the clamp at *c*, sections of mercury will flow down from the reservoir, and in so doing draw out portions of the air in the globe. These alternate sections of air and mercury pass down the tube into the flask *B*, the air escaping and the surplus mercury flowing into the basin. The weight of the mercury in the tube overcomes the pressure of the outside atmosphere and prevents it from entering. The operation is completed when it is found that no air can be enclosed, there being a solid column of mercury in the tube about thirty inches in height, or what is really a barometric column.

If the filament had not been sufficiently treated it is further *flashed* during exhaustion, and subjected to a high degree of incandescence.

Having been exhausted the small glass tube leading from the bulb is fused and the lamp sealed off.

**Resistance.** Carbon has the peculiar property of having a less resistance when hot than when cold. The resistance of an incandescent lamp when hot is readily determined by means of Ohm's law. Knowing the current passing through the lamp and the electromotive force at its terminals, the resistance will be,

$$R = \frac{electromotive\ force}{current}.$$

**Efficiency and Testing.** The efficiency of an electric lamp is measured by the amount of electrical energy consumed per candle power, or the **watts per candle power.**

To estimate the efficiency it is necessary to measure the energy consumed in the lamp at the same time that its candle power is measured. In doing this the voltage at the terminals is kept constant, and at that value at which the lamp is to work, the value of the current being recorded at regular intervals. From these values the average current is obtained which, multiplied by the voltage, gives the average energy in watts. In case the voltage at the lamp terminals cannot be kept constant, its value should be recorded at regular intervals from which the average voltage is obtained. The watts consumed by the lamp divided by the candle power gives the number of watts per candle power. The mean spherical candle power of an incandescent lamp is, of course, less than its mean horizontal, so that it is necessary to make a distinction between watts per mean spherical candle power, and watts per mean horizontal candle power, although mean spherical is usually understood.

For the same lamp the ratio of the mean spherical to the mean horizontal candle power is a constant, but this varies considerably for different types. For the Edison lamp this ratio is about .8. A good lamp should have an efficiency of 3.5 watts per mean spherical candle, hence a 32 c. p. lamp will require about 112 watts.

Commercial incandescent lamps are made for various voltages, usually 110 or less, and take a current of from half an ampere to an ampere. The usual candle powers are 16 and 32; on a 110 volt circuit the former takes about half an ampere and the latter one ampere. Lamps are marked by the manufacturers with the voltage at which they are to work and with the candle power.

The following table shows the approximate electromotive force and current required for various classes of Edison-Swan lamps, also the average watts per lamp and per candle power.

| Candle power. | Volts. | Amp. | to Volts. | Amp. | Av. watts per lamp. | Av. watts per c. p. |
|---|---|---|---|---|---|---|
| 1 | 8 | .8 | 8 | .3 | 2.4 | 2.4 |
| 2.5 | 5 | 1.4 | 25 | .45 | 9.1 | 3.6 |
| 5 | 5 | 3.0 | 65 | .35 | 18.9 | 3.8 |
| 8 | 10 | 2.8 | 120 | .3 | 32.0 | 4.0 |
| 16 | 15 | 3.7 | 160 | .4 | 59.8 | 3.7 |
| 25 | 40 | 2.2 | 120 | .7 | 86.0 | 3.4 |
| 32 | 50 | 2.3 | 120 | .9 | 111.5 | 3.5 |
| 50 | 50 | 3.5 | 120 | 1.4 | 171.5 | 3.4 |
| 100 | 50 | 7.0 | 120 | 2.9 | 349.0 | 3.5 |

**Life.** The "life" of incandescent lamps varies considerably depending largely upon the method of use. The less the strength of current passed through a lamp, the longer it will last, but the proportional increase in the illumination with an increase of current is much greater than that of the current. Hence a lamp has a higher efficiency the greater the expenditure of energy. Some lamps give out in a few hours while others can be made to burn several thousand hours, the average, however, is about 1,000 hours. The prolonged use of a lamp decreases its efficiency.

**Heat.** The heat developed in an incandescent lamp is about one-fifth of that of a gas jet of equal candle power.

Example.—A test of an Edison lamp showed its mean spherical power to be 22. The voltage was kept constant at 107, and the average current was found to be .7 ampere. *(a)* What was the resistance of the lamp? *(b)* The watts consumed? *(c)* The watts per candle power? *(d)* The number of such lamps supplied by one horse-power? *(e)* The number of candle power per H. P.?

Solution. — Resistance $= \frac{107}{.7} = 152.9$ ohms.

Watts $= E\,I = 107 \times .7 = 74.9$

Watts per c. p. $= \frac{74.9}{22} = 3.4$

Number of lamps per H. P. $= \frac{746}{74.9} = 9.96$

since one horse-power is equivalent to 746 watts.

Number of candles per H. P. $= 9.96 \times 22 = 219.1$

Ans. (a) 152.9 ohms.
(b) 74.9 watts.
(c) 3.4 watts per c. p.
(d) 9.96 lamps.
(e) 219.1 candles per H. P.

**High-voltage Lamps.** On page 26 the economy is shown of distributing electrical energy at high voltage. It would therefore be of great advantage if high-voltage lamps could be used. At the present time good incandescent lamps for operating on 220 volt circuits are obtainable in the larger candle powers, but the 220 volt lamp of 16 candle power or less is less economical than the 110 volt lamp.

**Series Incandescent Lamps.** Incandescent lamps are mostly made for connecting in parallel on constant potential mains, but lamps made for a constant current circuit, being connected in series, have to be quite differently manufactured. We shall take up later the methods of connecting lamps and assume it understood that a series lamp has a working current of from 5 to 10 amperes, and that since it is connected in series with other lamps, there must be some device to close the circuit if the lamp burns out or is removed, otherwise all the other lamps in series with it would be thrown out of use.

One of the best lamps for series working is the Bernstein. Since the filament must carry a comparatively large current, it is necessary that it should be of quite a large cross-section. In the Bernstein lamp the filament is made by carbonizing a silk braid of fine texture. This is connected to two pieces of iron wire and these again to the platinum wires which pass out through the

glass. The iron wires are subjected to the tension of a spring, so that when the filament burns out they will come into contact, closing the circuit. The holder is arranged in such a manner that before a lamp can be removed, a switch in the holder must be turned, short circuiting the lamp; also when no lamp is in the holder, this switch cannot be opened. This secures a closed circuit at all times.

**Advantages of Incandescent Lamps.** The most important advantages of incandescent lamps are: they do not vitiate the atmosphere, they give off but little heat, require only the turning or throwing of a switch to give the light the switch being located in any convenient position, they give a very steady light, there is no danger of setting fire to neighboring inflammable material, and they have a wide range of candle power.

Incandescent lamps can be operated on alternating current circuits as well as on direct current circuits.

## ARC LIGHTS.

**Principle.** The original method of lighting by electricity was by the electric arc. If a current of electricity of sufficient strength is passed through two pieces of carbon which are in contact and connected in series, and then if these are separated, there will be produced at this interruption in the circuit what is known as a **voltaic arc,** or simply **arc.** This gives out a white brilliant light, and has an intense heat.

Figure 4 shows the character of the arc and of the carbons after the current has continued for some time. The carbons are known as the **electrodes,** the upper one representing the positive electrode and the lower the negative electrode, the current passing of course from positive to negative. When the carbons are in contact, the current passes producing no perceptible effect; on drawing them apart the resistance is increased, and the temperature of the carbon tips is rapidly raised.

Fig. 4.

The heat thus caused vaporizes a portion of the carbon, and this vapor heated to incandescence forms the arc.

The vaporization takes place at the positive electrode and results in a cup-like hollow, or what is known as the **crater**, being formed in the positive tip. Although a large amount of light is emitted by the arc itself, and some by the negative electrode, by far the greater portion is given off by the positive electrode. For this reason the positive carbon should be above the negative so that the greater portion of the light will be cast downward. Since the tips are at a white heat and vaporization is always taking place, there must be a gradual burning away of the carbons. If the electrodes are of the same diameter, the positive will burn away about twice as fast as the negative, but if the positive has twice the cross-section of the negative about the same length of each carbon will be consumed.

**Temperature of the Arc.** The temperature of the arc is in the neighborhood of from 3,000° to 3,500° C. The crater has a higher temperature than any other part, and is at the boiling point of carbon. On account of this high temperature the most infusible substances such as flint and the diamond may be made to melt in the arc, and gold and platinum can be readily vaporized.

**The Carbons.** A good carbon should have great density, its structure should be uniform and free from impurities, and its resistance should be as low as possible. This will insure a uniform and slow consumption of the carbons, the arc will keep constantly centred about their axis, and the color of the light will remain the same. The color of the light depends upon the **material** of which the electrodes are made, and if impurities are present the color of the light will vary considerably.

The general process of manufacturing carbons is to mix with finely pulverized coke, pure carbon powder obtained by the destructive distillation of tar or pitch. To this is added a syrup to make the particles adhesive, the carbon rods being formed by forcing the mixture through a die plate. They are then baked several times to drive off all volatile gases, and to decompose the carbonaceous compounds. To make the carbons last longer they are often coated by electroplating, with a thin layer of copper, which also lowers the resistance of the rods and tends to make them burn

away more evenly. The latter advantages are also gained by the use of **cored carbons.** These are made with an inner core of softer carbon, and of higher conductivity, than the outside layer.

The diameter of the rods varies according to the current they are to carry; the current generally used requiring rods having a diameter of from $\frac{3}{8}$ to $\frac{5}{8}$ inch.

**Arc Lamps.** There are two important requirements for an arc lamp.

*1.* When the current is switched on it must light itself. This is accomplished by having the carbons in contact when the current is switched on, otherwise the current could not leap across the air gap. The current being allowed to flow, the carbons are separated a little and the arc formed, this separation being brought about through the agency of an electromagnet.

*2.* Since the carbons burn away gradually, there must be some arrangement to move the carbons towards each other as they are consumed, keeping the distance between the electrodes a constant. This **feeding** is accomplished by various mechanisms in the different lamps, the electromagnet being much used.

If it is required that the arc is to remain in a fixed position, as in the focus of a mirror or lens, each carbon must be fed in the exact proportion of its consumption. Such lamps, known as **focusing lamps**, are used in lanterns, search lights, and light houses.

Since there are a great variety of regulators for arc lamps, we shall give here a description of a few typical forms, the principles of which will enable the student to readily understand any other devices. It will be understood that the following refers to lamps on constant current circuits.

**Clutch Lamp.** The Brush arc lamp presents a form of mechanism known as the clutch feed. It is a **differential** lamp, the regulation being effected by the action of opposing currents in the magnet spools. A diagram illustrating the principle is given in Fig. 5. *P* represents the positive terminal of the lamp and *N* the negative. The carbons are represented by *a* and *b*, *a* being the positive. The clutch is shown at *c* and *d*; *c* being a washer which fits loosely over the positive carbon-holder and is held loosely in the fork *d*. This fork is attached to the pivoted piece

*e* which is joined to the soft iron cores of the coils *f* and *g*. The main current passes from *P* to *h* where it subdivides and passes through coarse wire low resistance coils *f* and *g*, which are wound oppositely so as to give unlike poles at their lower ends and make a powerful magnet. The current unites at *i* passing through the

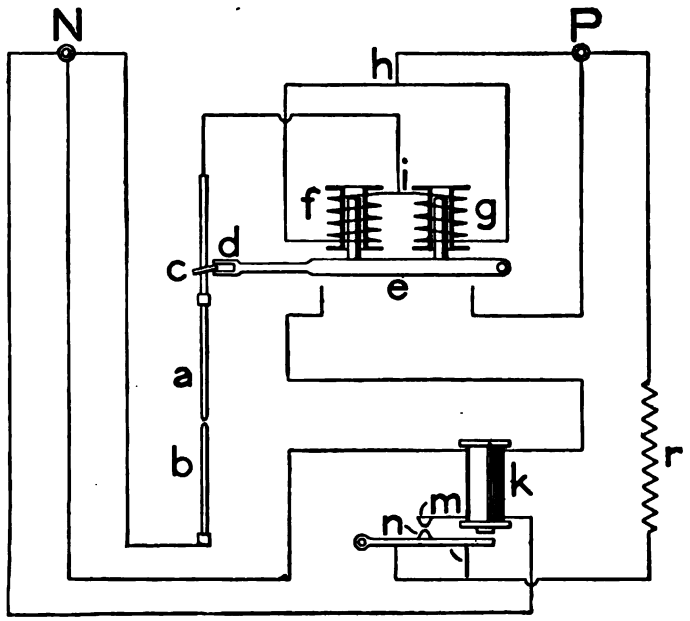



Fig. 5.

carbons to the negative terminal. A fine wire of high resistance passes from the positive terminal around *f* and *g* in series, these fine wire coils being over and in opposite direction to the coarse wire windings. To avoid confusion these outside coils are not shown in the figure. The wire then passes to the electromagnet *k*, forming the fine wire coil upon it, and is then connected to the negative terminal, so forming a shunt connection about the carbons.

With no current passing, the carbons will be in contact, gravity causing the upper carbon to fall against the lower. When the current is switched on, it will pass through the coarse windings of *f* and *g* in parallel, thence through the carbons to the negative terminal. As the cores of *f* and *g* are drawn inward, being magnetized by the current, the piece *e* will be raised, and

cause the washer *c* to be tilted a little, and as this then grips the carbon-holder it will be raised and the arc formed. Under normal conditions about one per cent of the total current passes through the fine wire coils. As the carbons burn away the length of the arc increases and a higher electromotive force is required at the lamp terminals, for the resistance is increased and the current of the line circuit is always constant. The shunt coils having a higher electromotive force at their terminals take more current, the coarse wire coils losing an equal amount. As they are wound oppositely the former overbalances the effect of the latter, and the soft iron cores fall gradually. This causes the clutch to loosen its grip on the carbon-holder allowing it to fall. As the carbon falls the resistance of the arc is decreased, causing a drop in the electromotive force; the effect of the coarse wire coils is now greater than that of the shunt coils, and the carbon-holder is again held by the clutch and raised to the proper position.

In order that the circuit through the lamp will always be closed so as not to throw other lamps on the circuit out of use, in case the carbons burn out or if the lamp gets out of order, there is an additional connection. This is from *P*, through the resistance coil *r*, to the pivoted lever *l*. This lever has upon it a contact piece *n*, which when raised, strikes another piece *m*. A coarse wire from *m* passes around *k* a few times, and then leads to *N*. In case the current for any reason is prevented from going through the carbons, it must go through the shunt circuit. Since this includes a coil on *k*, this large current going through it will cause the lever *l* to be raised, and contact will be made between *n* and *m*. A path for the main current is now made through *r*, *l*, *n*, *m*, around *k* to *N*, this circuit having a resistance equal to that of the lamp. It is evident that a few turns of this wire around *k* are necessary to keep *m* and *n* in contact, since it takes the current from the fine wire coils. When the carbons again come in contact this circuit loses most of its current; *l* then falls and the circuit is broken at *n*.

Lamps usually have a single set of carbons, but for long periods of lighting a double set is sometimes used, the second set being brought into use after the first has burned away. The clutch arrangement for this purpose is shown in Fig. 6. The upper

carbon-holders, $t^1$ and $t^2$, are each furnished with a washer clutch, as shown at $w^1$ and $w^2$. These clutches are operated by a small frame $u$, which is supported by the lever $e$ shown in Fig. 5 and in cross-section in Fig. 6. By making one of the forks in the frame $u$ wider than the other, the wider one allows its clutch to tilt before the other begins to act, and therefore lifts its carbon-holder a greater distance than does the other. At the moment the first carbon is raised, the entire current flows through the other, which is then also raised. Thus the arc is established across the lesser distance, and although both positive carbons are raised and lowered in subsequent feeding, the pair of carbons across which the arc was first formed are alone affected, for the ends of the reserve carbons never come into contact, and the electromotive force is insufficient to start an arc across the air space which separates them. When one pair of carbons has been so far consumed that they cannot meet when the frame falls, the circuit is completed through the reserve pair, and the arc established, after which it is maintained by the same apparatus acting in the same way as with the first pair.

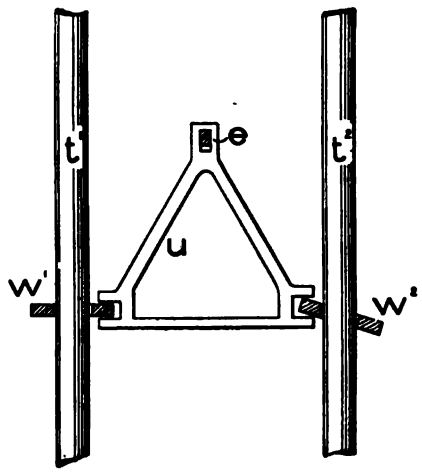


Fig. 6.

**Clockwork Lamps.** One of the common forms of regulator is that in which a clockwork mechanism is used. A spring, or even the weight of the carbon-holder, propels a train of wheels which gears with a pinion, and this in turn with a rack to which is attached the positive carbon. The armature of an electromagnet which is in series with the carbons and has also a shunt coil, regulates the action of this mechanism.

**Brake-wheel Lamp.** Fig. 7 shows the principle of one form of brake-wheel regulator. The wheel is represented by $W$, the lever governing its action by $L$, an electromagnet by $E$, having

its core $C$ attached to the lever. The coil $E$ is in series with the carbons. When no current flows, $L$ is in its lowest position, the wheel is released, and the carbons are in contact. When the current is thrown on, $C$ is drawn upwards, and the lever being raised grips the wheel turning it back slightly, so separating the carbons. A fine wire shunt coil (not shown) wound on $E$ in an opposite direction to the other winding is connected across the terminals. This regulates the feeding as in the Brush lamp. When $L$ is lowered the wheel is released and allowed to turn forward until the lever is again raised.

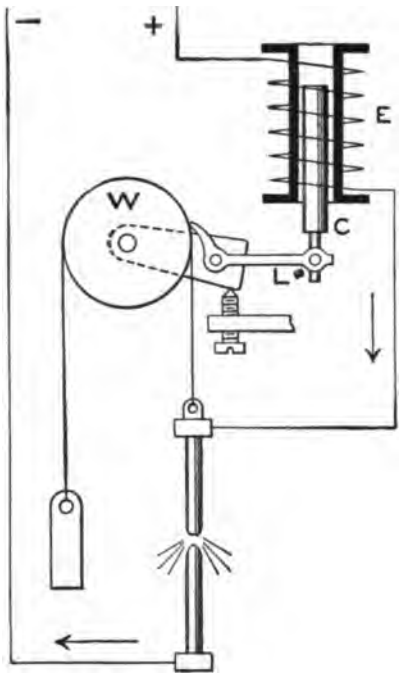
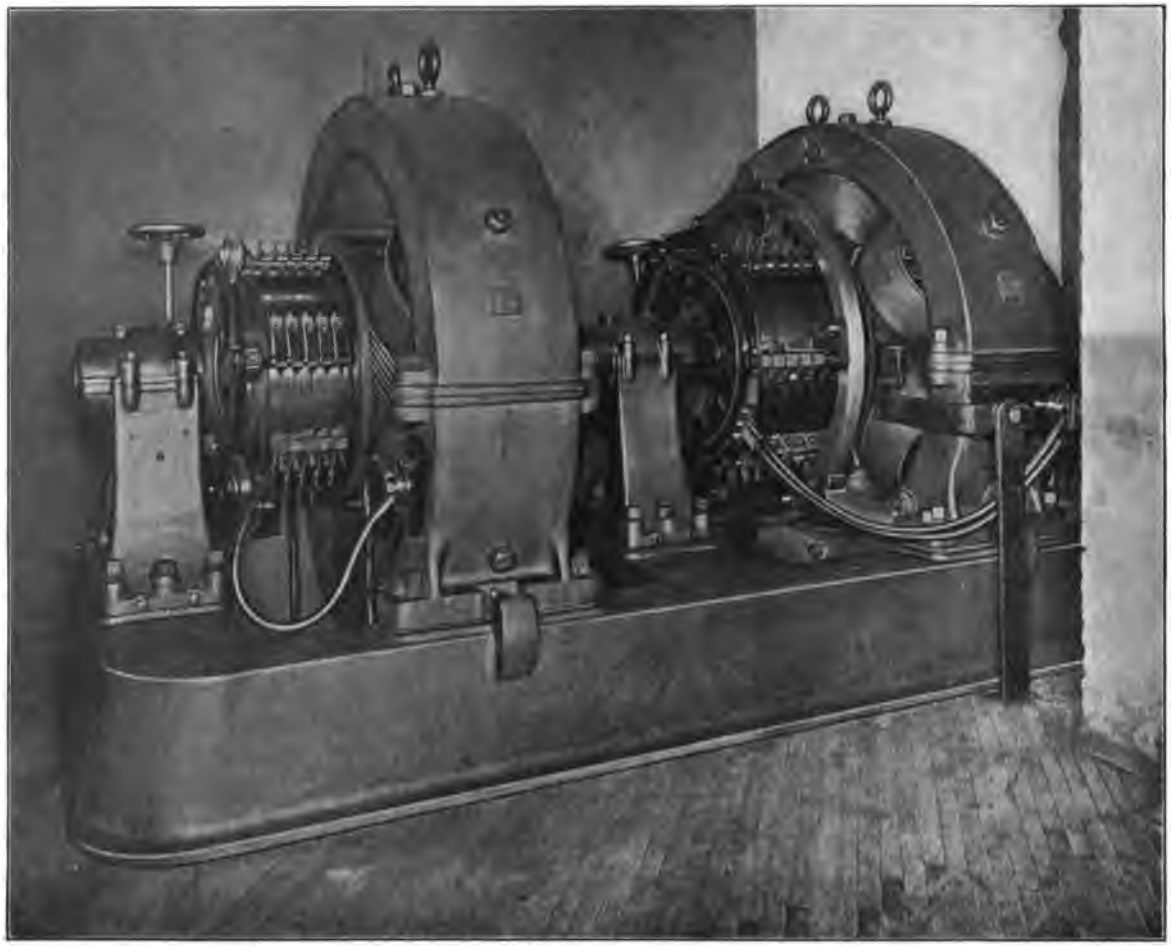


Fig. 7.

**Arc Lamps for Constant Potential Circuits** can be simpler than constant current lamps, as they do not need the fine wire shunt coil. If many lamps are connected in parallel however, the amount of current required in the mains becomes so great, that the great $I^2 R$ loss and the cost of the mains to carry this large current cause this system to be little used for arc lamps. It is very convenient sometimes to connect a *few* arc lamps on a constant potential circuit, and across a 110 volt circuit two arc lamps are usually connected in series. In order that when the resistance of the arc varies the proportional change in the current will not be much, a small steadying resistance is put in series with the lamps. This resistance is often arranged as a part of the lamp.

Problem. — Two arc lamps requiring 50 volts each which take a current of 9.6 amperes, are to be connected in series on a 110 volt circuit together with a steadying resistance. What must be the value of this resistance?



**Booster Used for Charging Storage Batteries. Used by the Electric Storage Battery Company.**

Solution.

Volts drop in this resistance $= 110 - 2 \times 50 = 10.$

Resistance required $= \frac{E}{I} = \frac{10}{9.6} = 1.04 +$ ohms.

Ans. 1.04 + ohms.

**Alternating Current Arc Lamps** are considerably used. Since the direction of the current is constantly changing, one carbon is just as much positive or negative as the other, and an equal amount of light is given from each electrode. The mechanism of the regulator is but slightly different from that of direct current lamps, the important difference being that the cores of the electromagnets are made short and **laminated** in order to reduce self-induction and eddy currents as far as possible, so enabling them to give a quick response to the changes in direction of the current.

**The Current and Voltage Required by Arc Lamps** in general use vary from three to ten amperes and from forty to eighty volts. The usual voltage is however, about 45 or 50. As arc lamps are mostly run on constant current circuits, being connected in series, a high voltage is required. For example, if 30 lamps are connected in series and each requires 50 volts, an electromotive force of 1,500 volts must be supplied by the dynamo.

**Enclosed Arc Lamps.** The ordinary arc lamp will burn several hours without any attention or renewal of the carbons, and a double set of carbons still further prolongs this time. **Enclosed** arc lamps burn 100 or even 150 hours without renewal. Such lamps have the arc enclosed within an inner small glass globe which, protecting the arc from winds and allowing it only a limited supply of oxygen, greatly increases the time in which the carbons are consumed. After burning some hours without cleaning, however, the collection of unconsumed carbon dust on the surface of this small globe seriously cuts down the effective illumination.

**Candle Power of Arc Lamps.** This depends mainly upon the strength of the current, the length of the arc, the nature and size of the carbons, and the nature of the globe, if any, surrounding the arc.

Fig. 8 shows the character of the **distribution** of light about the carbons when a direct current is used. The maximum candle

power is seen to be in the direction of about 50° downward, also almost the whole of the light is cast below the horizontal. In the case illustrated the maximum candle power was found to be 1050, and the mean spherical candle power 410, and it may be taken generally that the mean spherical candle power is about .4 of the maximum.

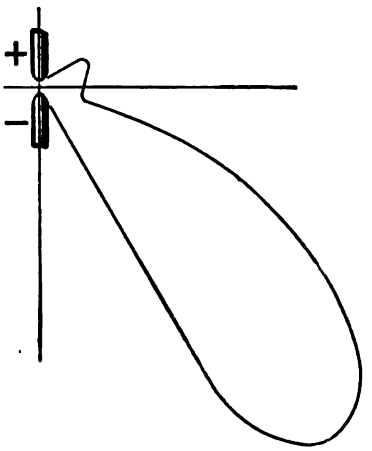


Fig. 8.

As it is very difficult to measure with much accuracy the illuminating power of an arc lamp, they are usually rated nominally. What is ordinarily known as a 2,000 candle power arc lamp is one requiring an average of 450 watts for its maintenance, and a 1,200 candle power lamp requires 300 watts, the measurements being made at the lamp terminals if no sensible resistance is included in series with the arc. In case such a resistance is used it should be excluded in the measurement of the voltage.

A lamp rated at 2,000 candle power has a mean spherical candle power of about 400. The number of watts required per candle power is therefore, $\frac{450}{400} = 1.125$. As a good incandescent lamp requires 3.5 watts per candle power, it is evident that an arc lamp is about three times as efficient as an incandescent.

The use of a globe considerably reduces the effective candle power of an arc lamp, the proportion of light cut off by its use having been found to be:

By clear glass, 10%.
By light ground glass, 30%.
By heavy ground glass, 45 to 50%.
By strong opal glass, 50 to 60%.

The testing of an arc lamp is very similar to that of an incandescent. The standard of comparison used is an incandescent lamp of known candle power, this being necessary, for, if the arc light was compared directly with a small standard it would lead to large errors in the result. Another feature is that the light from

the arc is first cast upon a mirror which reflects it upon the disk of the photometer, this arrangement being necessary in order to allow measurements to be taken in all directions about the arc. The mirror absorbs and disperses a portion of the light falling upon it from the arc, and the observed candle power must be multiplied by a constant or **mirror factor** to give that which would have been found without the mirror. Also the distance from the disk to the arc is the distance from the disk to the centre of the mirror, and from there to the arc.

**Use and Advantages of Arc Lamps.** Arc lamps are mostly used for lighting streets, halls, shops, stores, or in general where large areas are to be lighted.

The arc lamp may be easily and cheaply installed, particularly in regard to wiring. It is a very efficient light, and lamps can be made of almost unlimited candle power. The color of the light is almost pure white, closely resembling sunlight, and is, therefore, desirable in shops and factories where colors are to be brought out in their true relation.

On account of its great power and simplicity of wiring needed, the arc lamp is often used for temporary illumination where work is being done in excavations or in buildings at night.

## SYSTEMS OF DISTRIBUTION.

**Series Distribution.** In Fig. 9 is represented the series system, which was the one first used, and is also the simplest. This requires a **constant current** generator, the same current going successively through each arc and incandescent lamp on the circuit. This method of connecting requires the electromotive force of the generator to equal the **sum** of the electromotive forces of all the lamps in the circuit, that is, if there were 60 arc lamps on the circuit each requiring 45 volts, the E.M.F. of the generator must be at least 2,700.

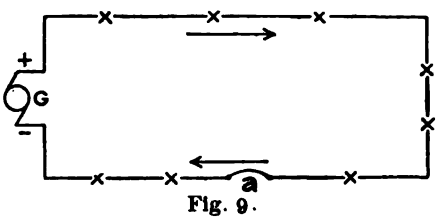


Fig. 9.

The **advantages** of this system are its simplicity, and its convenience in carrying power considerable distance with small loss.

The current being small, the conductor may be of small size and correspondingly small cost.

The disadvantages are the danger due to the necessarily high E.M.F. and the fact that a break in the circuit throws the whole system out of use. The lamps, however, as already described, always have devices for keeping the circuit unbroken if the lamp itself gets out of order. Motors can be run on series circuits if provided with a suitable governor, but they are seldom used.

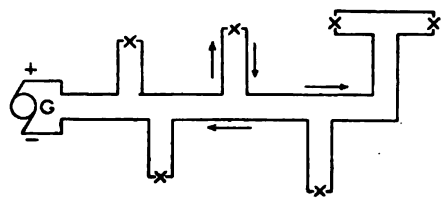


Fig. 10.

If single wires were run as in Fig. 9, there would be required, in case of a break, a connection around this point as at *a*. For this reason the better arrangement of the mains is as in Fig. 10. This allows a cross connection to be easily made when necessary, and also new lamps are easily inserted.

The series system is used mainly for street lighting and for arc lights.

**Multiple Series System.** This system, which is now but little used, is illustrated in Fig. 11. A number of branches, with lamps in series on each branch, are connected in parallel. The E.M.F. of the generator must be constant and equal to the total E.M.F. required by all the lamps in one branch. At the generating station an ammeter in each branch indicates the current. If this goes above the normal conditions, it means that some of the lamps on that branch have been switched off, and to reduce the current, lamps are switched on at the station.

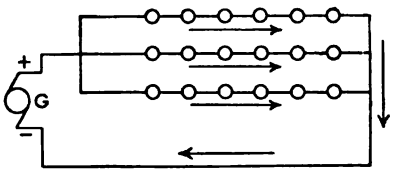


Fig. 11.

Objection is made to this system on account of this wasted energy when the load could be light, and also the high E.M.F. if introduced into dwellings becomes dangerous.

**Parallel System.** The parallel or multiple system of wiring is the most common, and is represented by Fig. 12. A **constant potential** dynamo is required, the lights being put in parallel between the mains. The switching on or off of a lamp does not

affect the others, and since the potential is constant for any load, the current varies directly as the number of lamps in circuit.

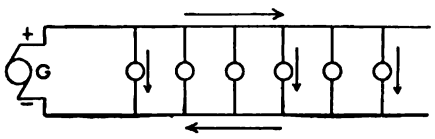



Fig. 12.

This system is quite generally adaptable, as incandescent lamps, arc lamps, motors, or secondary batteries can all be connected across the mains without producing any harmful effect upon each other. If the voltage is kept at 110, then all lamps, etc., are subject to this voltage. On account of the low voltage of this system it is much used in wiring buildings of all descriptions.

The system may be further extended by branches, taps and sub-taps, as shown in Fig. 13.

**Drop of Potential.** When a current flows through any resistance, a certain E.M.F. is required, hence in transmitting a current through any distance there will be a certain **drop** of potential

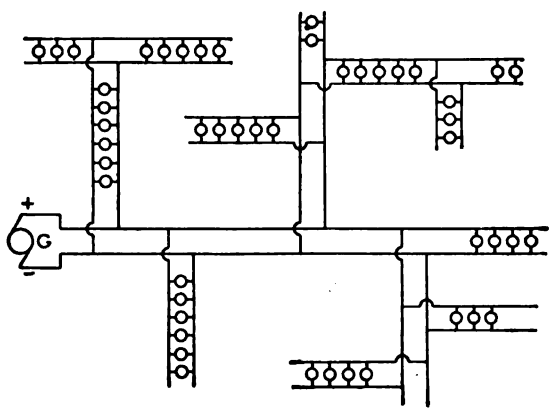



Fig. 13.

in the line, and this will vary directly as the product of the current and resistance, or as $I\,R$. Hence in the parallel system, lamps at a distance from the generator will receive a less voltage at their terminals than those near to it, and if the voltage of the generator was such that the distant lamps received their proper voltage, the voltage of nearer ones would be too great, and their life shortened.

**Loop System.** A system of wiring known as the loop sys-

tem overcomes this difficulty somewhat, by having the same length of circuit through each lamp from the positive terminal of the generator to the negative. This arrangement, as shown in Fig. 14, has the return wire run from the most distant lamp in the circuit to the generator. By referring to the figure it is evident that the current through each lamp has to pass through the same length of wire from the generator, through the lamp, and to the generator. On account of the fact that the drop depends upon the strength of the current as well as upon the different parts of the circuit will vary greatly, depending on the number of lamps on or off, the potential at each lamp will not always be the same. Also the long length of return wire required is an objection.

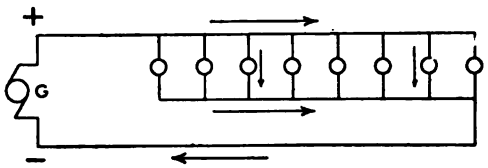


Fig. 14.

**Feeders.** The most common method of raising the potential at points where the drop is too great is by running large feed wires, or feeders, to those points direct from the station. These feeders will then carry a part of the total current, and having a higher voltage than the main conductors, the potential at points to which they run will be raised. From these points there leads back to the station small voltmeter wires, or **pilot** wires, and from the indication of the voltmeter the potential at these places can be ascertained.

If the potential at a point rises above the normal, the potential of the feeder must be reduced, if the potential is too low, that of the feeder must be raised. This change of voltage is accomplished by the use of an additional generator known as a **booster,** which has a voltage equal to the maximum required. From the positive potential bar, or positive **bus bar,** of this dynamo, the feeders lead to the points of supply. The potential of each feeder may be lowered by inserting resistance, or by the application of a counter E.M.F. at the station.

**Advantage of a High Potential.** This will be readily seen by taking an example where a low potential is used, and then a similar one where a higher potential is used.

Suppose the mains from a 110 volt generator run to four lamps connected in parallel, each lamp taking .5 ampere, and that the resistance of the mains is 10 ohms. What percentage of energy supplied is lost in the mains, and what is the percentage drop?

Solution.—Since each lamp takes .5 ampere, the current in the mains will be 2 amperes, and as their resistance is 10 ohms, the loss of energy in the mains, which disappears as heat, is

$$I^2 R = 2^2 \times 10 = 40 \text{ watts.}$$

The energy supplied is

$$E I = 110 \times 2 = 220 \text{ watts.}$$

The percentage lost is equal to

$$\frac{40}{220} \times 100 = 18.18+.$$

The drop in the mains is

$$I R = 2 \times 10 = 20 \text{ volts.}$$

The percentage drop is

$$\frac{20}{110} \times 100 = 18.18+.$$

Now suppose that instead of using a 110 volt generator there is used a 220 volt machine, and that the four lamps are connected two in series across the mains. What will the percentage loss be in this case?

Solution.—Since the lamps are connected two in series, the current in the mains will be only 1 ampere. The energy lost in the mains will be

$$I^2 R = 1 \times 10 = 10 \text{ watts.}$$

The energy supplied is

$$E I = 220 \times 1 = 220 \text{ watts.}$$

The percentage lost is equal to

$$\frac{10}{220} \times 100 = 4.54+.$$

The drop in the mains is

$$I R = 1 \times 10 = 10 \text{ volts.}$$

The percentage drop is

$$\frac{10}{220} \times 100 = 4.54+.$$

From this comparison it appears that the percentage loss of energy and the percentage drop were only **one-fourth** as much

where the higher potential was used although about the same amount of energy was consumed in the lamps. Therefore we could use mains having a resistance four times as great in connection with the higher electromotive force and then have only the same percentage loss as was the case with the lower potential, that is, we could use a wire whose cross-sectional area was only one-fourth as great.

It is evident that if a parallel system had a voltage high enough to allow **groups** of incandescent lamps to be connected in parallel across the mains, the lamps in each group being connected in series, there could on account of the small current, be a considerable saving in the cost of the wire and in the amount of energy wasted. The objection to this system is that if one of the lamps burns out, the others in series with it will be thrown out of use, or if this lamp was short circuited the remaining ones would take too much current. An automatic arrangement to switch in another lamp, or equal resistance, will not always give satisfaction, and causes extra expense and trouble.

**Three-wire System.** The advantages of a high potential can be had by the use of this system, which is represented by Fig. 15. Two similar generators are connected in series, and in

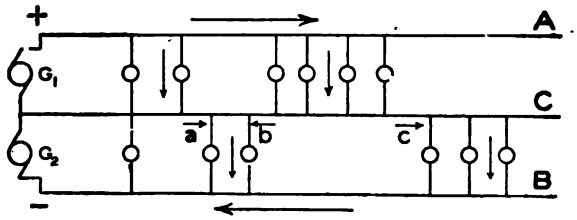



Fig. 15.

addition to the positive and negative wires *A* and *B*, there is a third wire *C*, known as the **neutral**, which is joined to the connection between the two machines. If each generator is of 110 volts, the voltage between *A* and *C*, and between *C* and *B* will be 110, while between *A* and *B* the voltage will be 220. The lamps are connected between the neutral and the outside wires, and the turning on or off of any one lamp does not affect any other. There is a further advantage of having **two voltages** available allowing the operation of 110 or 220 volt motors.

If the same number of lamps were on between *A* and *C* as between *C* and *B*, there would be no current in *C* except in short sections as at *a*, *b*, *c*, etc., and the direction and magnitude of these may happen to be quite different. If more lamps are on one side of *C* than on the other, the difference between the currents in the outside wires will be the main current in *C*. If twice as many lamps are on between *A* and *C* as between *C* and *B*, generator No. 1 will be doing twice as much work as the other. The nearer the two sides are balanced the greater will be the advantage gained by this system, therefore in the wiring the aim should be to connect the lamps in such a way that an equal number will be in use at the same time on each side of the neutral wire.

The principal objections to the use of this system are: it requires two dynamos, three wires are necessary, greater precautions must be taken in the insulation of the wires, and for good results it is necessary to have the system well balanced. If the system was at all times balanced or very nearly so, there would be no need of running the neutral wire to the generators.

**Five-wire System.** The principle of the three-wire system

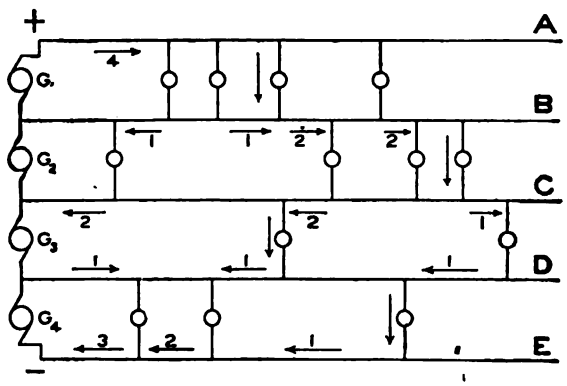



Fig. 16.

may be extended to the five-wire system which is represented by Fig. 16. Four generators are connected in series and five wires used. There are four different voltages available. If the voltage of each dynamo is 110, then there is between adjacent wires 110 volts, between *A* and *C*, *B* and *D*, and *C* and *E* 220 volts, between *A* and *D*, and *B* and *E* 330 volts, and between *A* and *E*

440 volts. In such a system the direction and magnitude of the current in different sections is very variable. In the figure the arrows indicate the direction of the current and the numbers, the strength of the current, assuming that each lamp takes one ampere.

The advantages of this system are considerably offset by the great expense in installing it, and it is but little used.

The **seven-wire** system which is still more costly to install requires six dynamos.

**Alternating Current System.** This will be but briefly referred to here leaving to a following work a fuller description and explanation. In lighting large areas or widely separated sections, the application of the alternating current is very general. The dynamo has a high E. M. F., 1,000 or more, and the current is transmitted at this high voltage to points of distribution, by a comparatively small wire with but little loss. By means of **transformers** this high voltage is reduced to a safe one for wiring buildings, etc., and to these low potential circuits the lamps are connected.

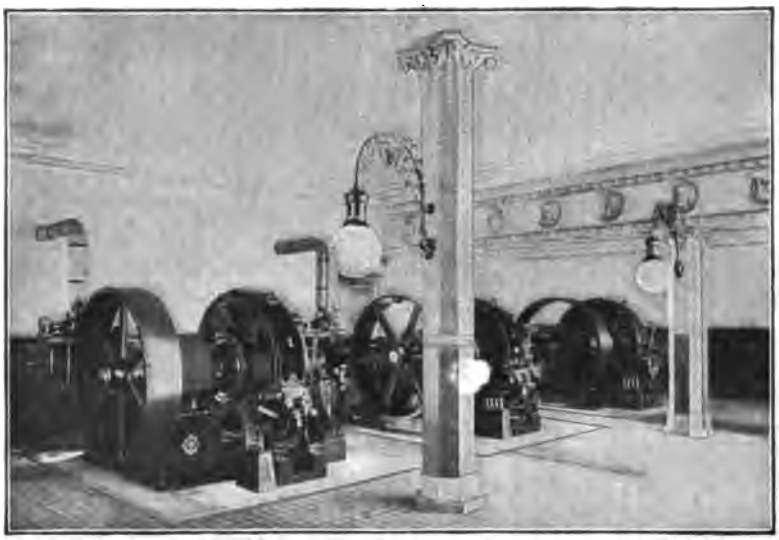
**Selection of a System.** This depends upon the particular conditions that exist in each case, whether arc lamps, incandescents, or both are to be used, the extent of area to be lighted, distance of the plant from this area, and many other circumstances.

Where arc lamps are to be almost entirely used as in street lighting, the series system, on account of its simplicity and small cost of installing, is by far preferable.

For general lighting where the station is within the district to be lighted, and the area to be covered is small, the low pressure two-wire system is found the most satisfactory. With the aid of feeders and boosters, it is practicable to supply lamps at a distance of one-third of a mile from the station.

The three-wire system can extend a mile or a mile and a half from the station, so that if this is centrally located a circular area having a diameter of 2 or 3 miles may be supplied. In large cities it is customary to locate several stations in different sections, each station supplying power to its own district.

Where the station is located several miles from the centre of distribution, it is found necessary to use the high pressure alter-



**TYPICAL INSTALLATIONS OF WESTERN ELECTRIC COMPANY'S GENERATORS.**

nating current system. This system would also give the best economy where buildings to be lighted are very much scattered, or where neighboring towns are to be supplied by one station.

**The Location of Lamps.** The number and location of lamps in lighting any building is largely a matter of taste and judgment. To give a **brilliant** illumination a 16 c. p. lamp is required for every 900 cubic feet of space. To give an **ordinary** light the following table, giving the number of 16 c. p. lamps required for rooms of different dimensions, will be found a good guide.

| Dimensions of Room, in Ft. | | | No. of 16 c. p. Lamps. | Height of Lamp Above Floor, in Ft. |
|---|---|---|---|---|
| Length. | Width. | Height. | | |
| 15. | 15. | 12. | 1 to 2 | 6.5 to 7.0 |
| 18. | 18. | 14. | 4 " 5 | 7.0 " 7.5 |
| 24. | 24. | 17. | 7 " 9 | 8.0 " 9.5 |
| 33. | 33. | 22. | 12 " 15 | 9.5 " 10.5 |
| 41. | 41. | 31. | 19 " 22 | 11.0 " 12.5 |
| 52. | 52. | 41. | 30 " 34 | 13.0 " 14.5 |
| 63. | 63. | 46. | 45 " 53 | 15.0 " 17.5 |
| 72. | 72. | 52. | 75 " 90 | 18.0 " 20.5 |

If 32 c. p. lamps are to be used instead of 16, a little more than half of the number given in the table would be required. The number of lights required for rooms varies considerably according to their use. Offices and reading rooms require considerable light, and the lamps must be localized near the desks and tables. Show windows must have a brilliant illumination and the best effect is produced when lighted by reflected light only. A general illumination is necessary for stores, lobbies, and halls.

Where arc lamps are used in lighting cotton mills, woolen mills, printing works, etc., a 1,200 c. p. lamp is required for every 7,000 to 9,000 square feet; in general engineering shops one lamp is sufficient for every 13,000 to 18,000 square feet.

**Horse-power Required.** Having a system of lamps to be supplied with energy the size of the necessary dynamos and engines may be arrived at in different ways. One method is to allow 3.5 or 4.0 watts per c. p. for incandescent lamps, then, knowing the number of lamps and their candle power, the total energy required may be computed.

Example. — There are installed 600 incandescent lamps of 16 c. p., and 100 lamps of 32 c. p. Assuming 4.0 watts required per c. p., what energy in watts will the lamps consume? In horse-power?

Solution. —

Total c. p. of all the 16 c. p. lamps $= 600 \times 16 =$ 9,600
Total c. p. of all the 32 c. p. lamps $= 100 \times 32 =$ 3,200

Total 12,800

Watts required $= 12{,}800 \times 4 = 51{,}200$ or 51.2 K. W.

Horse-power $= \frac{51{,}200}{746} = 68.6 +$

Ans. { 51,200 watts. 68.6 + H. P.

A simpler method is to find the total current required by all the lamps, then knowing the voltage at which they work, their product will give the watts required.

Example. — Suppose we are to install a 110 volt parallel system. There are to be used 600 incandescents of 16 c. p. which we know take .6 ampere at 110 volts; 100 of 32 c. p. which take 1.1 amperes; also there are to be 10 arc lamps which take 6.0 amperes and these are connected two in series to the mains. What is the number of kilowatts needed, and what horse-power?

Solution. —

Current required by the 16 c. p. lamps $= 600 \times .6 =$ 360 amp.
Current required by the 32 c. p. lamps $= 100 \times 1.1 =$ 110 amp.
Current required by the arc lamps $= \frac{1}{2} \times 10 \times 6.0 =$ 30 amp.

Total current 500 amp.

Watts required $= 500 \times 110 = 55{,}000$ or 55 K. W.

Horse-power $= \frac{55{,}000}{746} = 73.7 +$

Ans. { 55 K. W. 73. 7 + H. P.

If both current and voltage are known, the solution reduces to the finding of a simple product.

Example.— A 110 volt parallel system is to be installed with 860 incandescent lamps of 16 c. p., and 84 of 32 c. p. How many kilowatts will be required to supply the lamps, assuming them to take a current of 0.6 and 1.1 amperes each respectively?

Solution.—

For the 16 c. p. lamps, $860 \times 0.6 \times 110 = 56{,}760$ watts.

For the 32 c. p. lamps, $84 \times 1.1 \times 110 = 10{,}164$ watts.

Total watts required $= 66{,}924$

Total kilowatts required $= 66.924$

In the above examples we have considered only the energy consumed by the lamps themselves, having made no allowance for the $I^2 R$ loss in the wiring, and this might be great or small according to the distance the power is transmitted, and according to the size of the wire. In general, about 10 lamps of 16 c. p. are allowed for every indicated horse-power of the engine. Also a liberal allowance should usually be made for future extension.

In the series system the dynamo must be such as to keep the current constant. The strength of current being known, the number of lamps on the circuit determines the voltage that is necessary.

## ELECTRIC LIGHTING PLANTS.

**The Location.** This is determined sometimes by the system of distribution adopted, or the location of the station may determine the system, as when water power is to be used which is only available at a distance. If a low pressure system is used the station must be within or very near the district to be lighted, and the size and nature of the district may still further determine its site. Among other considerations must also be considered such points as convenience of coal and water supply, possibility of obtaining good foundations and chimney draught, cost of ground space, and whether or not there is room for future extension.

**The Boilers.** A boiler used in connection with electric lighting should maintain a constant pressure, especially at full load. A slight variation in this, would, on account of change of speed of the dynamo, produce a perceptible fluctuation in the brilliancy of the lamps. Also the boiler must be of a type which will take care of wide changes in the load. A boiler having a large heating surface and small water capacity can get steam up quickly, and so fulfills this condition; for this reason water-tube boilers are much used in electric lighting plants.

**The Engines.** In an electric light station the load is usually very light during the day and after midnight, and is a maximum

for a few hours only. For this reason it is very desirable, unless the power supplied is small, to have several engines so that as the load increases their power may be successively added. The relative size of the units should be such as to enable them to work at their full capacity when in use, but in an electric light station this is very difficult and proves to be a serious obstacle to good economy. In some cases it is advisable to have all of the units of the same capacity, but the best economy is usually obtained where large units are used during heavy loads and small units during light loads. Where a shut down in the plant would cause trouble and expense, it is advisable to have one or two extra engines in case those in regular use were disabled or in need of repairs.

The type of engine to select is not easily determined, but for small sizes the simple non-condensing is used. The question of selecting a compound or triple expansion, condensing or non-condensing engine is one upon which there is considerable disagreement, and in a given case it is sometimes impossible to determine which would be the most advantageous.

**The Dynamos.** The type of the generator is, of course, determined by the system of distribution. The size and number of units is not of so much importance as in the case of the engine, for the efficiency of a dynamo does not decrease nearly as rapidly when the load becomes light. Even at one-third load the efficiency of some dynamos is not much less than at full load; also small dynamos are made nearly as efficient as those of large capacity. It is allowable then, to suit the number and size of the dynamos to the requirements of the engines.

**Direct Coupling of Engines and Dynamos.** The direct coupling of a dynamo and engine has great advantages as it is very simple, takes but little room, gives no loss of efficiency due to belting or counter-shafting, and also rids of the noise of belt-driven machinery. With a direct connection the dynamo must run at the same speed as the engine, and since the speed of generators is generally much higher than that of engines, the dynamo must run at a comparatively slow speed, and high speed engines must be used.

A dynamo designed to run at a slow speed has an armature of large diameter so as to give a high peripheral velocity, but even

then the low speed involves a sacrifice of output and economy. The advantages of direct coupling, however, often more than overbalance this objection, and in some cases on account of the small space, direct coupling is a necessity. Recently this form of connection has largely superseded belting.

**Use of Accumulators.** Accumulators or secondary batteries have been applied to electric lighting recently to a considerable extent. This is due to the wide variation in load. In general the load is very light from 1 to 5 A. M., is a little heavier during the day-time, rises rapidly at twilight, and after being at a maximum for about two hours, rapidly decreases. During certain parts of the day the load is so small as to require the operation of but one engine at one-half load or less, while on the other hand, the plant is worked for a short period only, at its full capacity. Accumulators may be used in several different ways; as in carrying the light load allowing the machinery to be stopped; in being brought into use together with the dynamos when the load is a maximum; in allowing the engines to be worked at their full capacity during periods of light load by charging the accumulators at the same time; and in supplying energy from local centres or sub-stations. Their application is, however, so recent that a longer experience with them is necessary to fully determine their advantages and disadvantages.

**The Switchboard.** The leads from each generator in the station all run to one centre of distribution which is the switchboard, and from it all the mains and feeders lead out to the external circuits. Here are all the switches for controlling the supply and the output, the instruments to indicate the current and voltage of each machine, and the safety devices. A full description of these instruments and the arrangement is taken up in following instruction papers.

## CONDUCTORS.

**Copper Conductors.** On account of the high conductivity, strength, and comparative cheapness of copper, it alone is the material of which the conductors used in electric lighting are made. The conductivity of copper, that is, the reciprocal of the specific resistance, depends upon the amount of impurities present,

and as for the same copper it varies according to the degree of hardness, it is convenient to specify the electrical quality of copper by its **relative** conductivity, that is, its conductivity expressed as a percentage of that of pure soft copper.

**Matthiessen's Standard.** In 1860 Matthiessen determined the specific resistance of what was supposed to be pure soft copper, and found the resistance of the meter-gram at 0°C. to be .14171 international ohms. It has since been found that the copper he used was not pure, as copper can now be obtained having a conductivity as much as two per cent higher; but as no other thorough investigation has been made, Matthiessen's determination has been universally adopted as the standard of reference. Hence it is possible to have copper with a conductivity as high as 102%.

To get the percentage conductivity of a sample, the resistance, temperature, length, and weight of the sample are measured. The resistance of the meter-gram at 0°C. is then computed, and the ratio of its reciprocal to the reciprocal of .14171 will, when multiplied by 100, give the percentage conductivity.

Copper has approximately a specific gravity of 8.89, weighs .321 pound per cubic inch, or 555. pounds per cubic foot, and and has a melting point of about 2,100°F.

**The Circular Mil.** The **mil** is equal to one thousandth of an inch, or 1 mil = .001 inch.

One **circular mil,** usually written *C. M.*, is the area of a circle which has a diameter of one mil. This area in square inches is $\frac{1}{4} \times 3.1416 \times .001^2 = .0000007854$.

Since the area of a circle varies as the square of the diameter, the cross-section of a wire 2 mils in diameter will have 4 times the area of that of a wire one mil in diameter, if 3 mils in diameter its area will be 9 times as great, etc. Hence in a wire 2 mils in diameter the cross-sectional area is 4 *C. M.*, in one 3 mils in diameter 9 *C. M.*, 4 mils in diameter 16 *C. M.*, etc. That is, the number of circular mils is equal to the square of the diameter in mils, or,

$$C.\ M. = d^2$$

Example. — What is the cross-sectional area in circular mils of a wire having a diameter of .0808 inch?

Solution. — .0808 inch = 80.8 mils.

$$\text{area} = \overline{80.8}^2 = 6528.+ \ C.\ M.$$

Ans. 6528.+ *C. M.*

On account of this simple relation between the diameter and the area these units are universally used in expressing the size of a wire.

**Gauge of Wire.** In this country the **Brown & Sharpe** gauge is in general use.

The size of **large** wires is usually expressed directly as so many circular mils.

The table on page 86 will be found convenient for reference. The resistance is given in the international ohm, which was adopted by the International Congress of Electricians in 1893. This unit is equal to 1.0137 B. A. units, and 1.0028 legal units. The resistance in the table is that at 20°C., or 68°F.; to change to any other temperature it is usually close enough to allow .4 per cent change per degree Centigrade, and .22 per cent per degree Fahrenheit.

Example. — What is the resistance of a foot of No. 14 (B. & S.) pure copper wire at 75°F.?

Solution. —

Resistance at 68°F. = .002521

Increase per degree = .002521 × .0022

= .0000055

Increase to 75°F. = .0000055 × 7

= .000039

Resistance at 75°F. = .002521 + .000039

= .002560 ohm.

Ans. .002560 ohm.

The resistance given in the table is that of pure copper wire; ordinary commercial copper has a resistance from 3% to 5% greater.

## AMERICAN, OR B. & S. GAUGE.

| Gauge No. | Diam. in Mils. | Area in Circular Mils. | Weight in lbs. per 1000 Feet. | Feet per Pound. | Resistance of Pure Copper in International Ohms at 20°C, or 68° F. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Ohms per Ft. | Ft. per Ohm. | Ohms per lb. |
| 0000 | 460.0 | 211600. | 640.5 | 1.56 | .0000489 | 20440. | .00007539 |
| 000 | 409.6 | 167800. | 508.0 | 1.97 | .0000617 | 16210. | .0001215 |
| 00 | 364.8 | 133100. | 402.8 | 2.49 | .0000778 | 12850. | .0001931 |
| 0 | 324.9 | 105600. | 319.5 | 3.13 | .0000981 | 10190. | .0003071 |
| 1 | 289.3 | 83690. | 253.3 | 3.95 | .0001237 | 8083. | .0004858 |
| 2 | 257.6 | 66370. | 200.9 | 4.98 | .0001560 | 6410. | .0007763 |
| 3 | 229.4 | 52630. | 159.3 | 6.28 | .0001967 | 5084. | .001235 |
| 4 | 204.3 | 41740. | 126.4 | 7.91 | .0002480 | 4031. | .001963 |
| 5 | 181.9 | 33100. | 100.2 | 9.98 | .0003128 | 3197. | .003122 |
| 6 | 162.0 | 26250. | 79.46 | 12.58 | .0003944 | 2535. | .004963 |
| 7 | 144.3 | 20820. | 63.02 | 15.87 | .0004973 | 2011. | .007892 |
| 8 | 128.5 | 16510. | 49.96 | 20.01 | .0006271 | 1595. | .01255 |
| 9 | 114.4 | 13090. | 39.63 | 25.23 | .0007908 | 1265. | .01995 |
| 10 | 101.9 | 10380. | 31.43 | 31.85 | .0009972 | 1003. | .03173 |
| 11 | 90.74 | 8234. | 24.93 | 40.12 | .001257 | 795.5 | .05045 |
| 12 | 80.81 | 6530. | 19.77 | 50.58 | .001586 | 630.5 | .08022 |
| 13 | 71.96 | 5178. | 15.68 | 63.78 | .001999 | 500.1 | .1276 |
| 14 | 64.08 | 4107. | 12.43 | 80.45 | .002521 | 396.6 | .2028 |
| 15 | 57.07 | 3257. | 9.86 | 101.4 | .003179 | 314.5 | .3225 |
| 16 | 50.82 | 2583. | 7.82 | 127.9 | .004009 | 249.4 | .5128 |
| 17 | 45.26 | 2048. | 6.20 | 161.3 | .005055 | 197.8 | .8158 |
| 18 | 40.30 | 1624. | 4.92 | 203.4 | .006374 | 156.9 | 1.296 |
| 19 | 35.89 | 1288. | 3.90 | 256.5 | .008038 | 124.4 | 2.061 |
| 20 | 31.96 | 1022. | 3.09 | 323.4 | .01014 | 98.62 | 3.278 |
| 21 | 28.46 | 810.1 | 2.45 | 407.8 | .01278 | 78.24 | 5.212 |
| 22 | 25.35 | 642.6 | 1.95 | 514.2 | .01612 | 62.05 | 8.287 |
| 23 | 22.57 | 509.5 | 1.54 | 648.4 | .02032 | 49.21 | 13.18 |
| 24 | 20.10 | 404.0 | 1.22 | 817.6 | .02563 | 39.02 | 20.95 |
| 25 | 17.90 | 320.4 | .97 | 1031. | .03231 | 30.95 | 33.32 |
| 26 | 15.94 | 254.1 | .77 | 1300. | .04075 | 24.54 | 52.97 |
| 27 | 14.20 | 201.5 | .61 | 1639. | .05138 | 19.46 | 84.28 |
| 28 | 12.64 | 159.8 | .48 | 2067. | .06479 | 15.43 | 133.9 |
| 29 | 11.26 | 126.7 | .38 | 2607. | .08170 | 12.24 | 213.0 |
| 30 | 10.03 | 100.5 | .30 | 3287. | .1030 | 9.707 | 338.6 |
| 31 | 8.928 | 79.71 | .24 | 4145. | .1299 | 7.698 | 538.4 |
| 32 | 7.950 | 63.29 | .19 | 5227. | .1638 | 6.105 | 856.2 |
| 33 | 7.080 | 50.13 | .15 | 6591. | .2066 | 4.841 | 1361. |
| 34 | 6.305 | 39.75 | .12 | 8311. | .2605 | 3.839 | 2165. |
| 35 | 5.615 | 31.52 | .10 | 10480. | .3284 | 3.045 | 3441. |
| 36 | 5.000 | 25.00 | .08 | 13210. | .4142 | 2.414 | 5473. |
| 37 | 4.453 | 19.83 | .06 | 16660. | .5222 | 1.915 | 8702. |
| 38 | 3.965 | 15.72 | .05 | 21010. | .6585 | 1.519 | 13870. |
| 39 | 3.531 | 12.47 | .04 | 26500. | .8304 | 1.204 | 22000. |
| 40 | 3.145 | 9.89 | .03 | 33410. | 1.047 | .955 | 34980. |

In case a table is not at hand, there is a simple method of obtaining the approximate resistance of a wire. It is only necessary to remember that a thousand feet of No. 10 wire have a resistance of 1 ohm. If in this gauge three is dropped in the number the resistance is half as much, if three is added to the number the resistance is doubled. That is, the resistance of No. 7 wire is $\frac{1}{2}$ that of No. 10, resistance of No. 4 is $\frac{1}{2}$ that of No. 7, or the resistance of No. 6 is $\frac{1}{2}$ that of No. 9. Also the resistance of No. 13 wire is twice that of No. 10, of No. 16 twice that of No. 13, of No. 15 twice that of No. 12, etc.

Example.—What is the resistance of 1,000 feet of No. 4 (B. & S.) copper wire?

Solution:

Resistance of 1,000 ft. of No. 10 = 1. ohm.
Resistance of 1,000 ft. of No. 7 = $\frac{1}{2} \times 1 = .5$ ohm.
Resistance of 1,000 ft. of No. 4 = $\frac{1}{2} \times .5 = .25$ ohm.

Ans. .25 ohm.

Example.—What is the resistance of 2,500 ft. of No. 16 (B. & S.) copper wire?

Solution:

Resistance of 1,000 ft. of No. 10 = 1. ohm.
Resistance of 1,000 ft. of No. 13 = 2 $\times$ 1 = 2 ohms.
Resistance of 1,000 ft. of No. 16 = 2 $\times$ 2 = 4 ohms.
Resistance of 2,500 ft. of No. 16 = 2.5 $\times$ 4 = 10 ohms.

Ans. 10 ohms.

Example.—If the resistance of 1,000 ft. of No. 9 wire is .79 ohm, what is the resistance of 3,000 ft. of No. 12 (B. & S.)?

Solution:

Resistance of 1,000 ft. of No. 9 = .79 ohm.
Resistance of 1,000 ft. of No. 12 = 1.58 ohms.
Resistance of 3,000 ft. of No. 12 = 4.74 ohms.

Ans. 4.74 ohms.

This could be solved approximately from the resistance of No. 10 wire, thus:

Resistance of 1,000 ft. of No. 10 = 1. ohm.
Resistance of 1,000 ft. of No. 13 = 2. ohms.

The difference is 1 ohm, hence for No. 12 wire, the difference between it and No. 10 would be about $\frac{2}{3}$ of 1 ohm, or $\frac{2}{3}$ ohm.

Hence, resistance of 1,000 ft. No. 12 = 1.66 ohms.
Resistance of 3,000 ft. No. 12 = 4.98 ohms.

Ans. 4.98 ohms.

If it is remembered that 1,000 ft. of No. 10 bare wire weigh 31 lbs., the weight of other sizes may be figured, for if three is dropped in the number the weight is doubled, if three is added the weight is only one-half.

Example.—What is the weight of 1,000 ft. of No. 13 (B. & S.) copper wire? Ans. 15.5 lbs. (approx.)

The wire table must be used for exact work, but approximate formulas are very convenient for rough calculations. Still another method may be given, based on the foot-mil as a unit. The foot-mil (or mil-foot) is a wire 1 foot long and 1 mil in diameter.

A foot-mil of ordinary commercial copper wire has a resistance of 10.3 ohms, and 1,000 feet of such wire weigh very nearly 0.003 pound. From this it is easy to calculate both the weight and resistance of a wire of any given diameter, for the weight per foot increases as the number of circular mils of this wire, and the resistance diminishes in the same proportion.

**Insulated Conductors.** For the proper insulation of conductors it is usually necessary that the wire should be coated with some material having a high insulation resistance. This insulation should be durable and waterproof, and should have a thickness depending upon the electromotive force the wire is to be subjected to. India-rubber or gutta-percha are mostly used, but there are many special insulating compounds. Gutta-percha cracks and its insulation deteriorates if exposed in a dry air. It also softens to a greater extent than rubber when heated. Paper makes a good insulating material if kept dry; it cracks when bent, however, and is hard to break open.

After the wire is coated with the insulating material, this is covered for protection and to make waterproof, with a braid of cotton or hemp and is then saturated with pitch, tar or resin.

**Stranded Conductors.** Large sizes of solid wire are difficult to handle. To give flexibility and to render them less likely to break, large conductors or **cables** are made stranded, that is, the conductor is made up of several small wires.

The carrying capacity of the cable is, of course, determined by the size and number of wires composing it. The number of wires is such as to make up a circle, or as near to it as possible, hence the cable may comprise 3, 7, 19, 37, 61, etc., wires.

Figure 17 shows a sectional view of an electric light cable designed for one of the mains of a three-wire circuit and for underground use. The stranded core is covered with the insulating material; in this case its thickness is about one-third of the diameter of the core. Outside of this material is a covering of

lead as indicated by the heavy circle, and then comes a coating of an impervious compound. For mechanical protection there is then a sheathing of iron and outside of this is a second layer of the impervious compound.

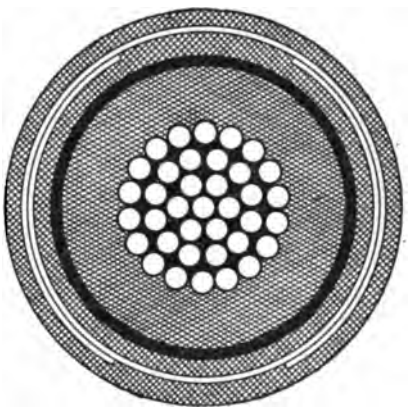


Fig. 17.

It is often convenient to avoid the use of too large a cable by joining several smaller ones in parallel. To determine what sizes of wire are needed to make up a certain size, it is only necessary to find from the table on page 36 the size of the wires which have the sum of their circular mils equal to the circular mils required.

Example. – Instead of using No. 0000 (B. & S.) wire, we wish to use several smaller ones joined in parallel, not using a smaller size than No. 3. What sizes could be used?

Solution.—Circular mils of No. 0000 = 211600. From the table we see that two No. 0 wires would equal the circular mils of No. 0000. Also that four No. 3 could be used, one No. 0 with two No. 3, or one No. 00 with one No. 1, these giving quite a close equivalent.

## OVERHEAD AND UNDERGROUND SYSTEMS.

The method of supporting, insulating, and protecting the conductors is divided into two systems according as they are overhead or underground.

On account of its cheapness in construction and its easy access for inspection, repairs, and extensions, the overhead system is by far preferable. In large cities, however, the use of the underground system is customary, and in some cases compulsory. This has been found necessary because a network of wires near a building makes it difficult of access in case of fire, and the danger from falling wires and short circuits by cross connections is very great. Moreover, the crowding of streets with wires is a great disfigure-

ment to a city. Also the insulation of the line in the overhead system is affected by changes in the weather, and during severe storms there is danger of a general breakdown.

To offset the advantages of the underground system are the objections of the great cost of installing, and the difficulty of access and extra cost in repairs and extensions.

**The Overhead System.** The **poles** supporting the wires are usually of wood, but iron poles are used to some extent, especially on prominent streets or where appearance is an important consideration.

Of wooden poles, planed pine present the best appearance, but they are likely to decay, lasting only about five years. Chestnut poles are strong, hard, and elastic, and last from ten to fifteen years. Treating the poles with creosote greatly prolongs their life.

The necessary length of a pole depends upon whether or not trees, houses, other lines, etc., have to be cleared. The distance between poles is usually from 100 to 150 feet.

**Cross pieces,** usually made of Norway pine, which support the pins, are bolted to the pole, and are often re-enforced by iron straps. Where great strength is necessary two cross arms are bolted on opposite sides of the pole and short studs fitted between the ends. To prevent decay it is customary to paint around the gains for the cross pieces and the top of the pole; in many cases the whole pole and the cross arms are painted.

The **pins,** made of wood or iron, are firmly fixed in the cross arm, and have threaded ends to receive the insulator. The number of pins on an arm, or their distance apart, depends upon the difference of potential between the mains. Where this is greater than 300 volts the pins should be at least one foot apart.

**Insulators.** To prevent, as far as possible, loss or leakage of current from the mains they are attached to insulators, these being supported by the pins. The requirements for a good insulator are a high specific resistance, hardness, smoothness, imperviousness to moisture, and a form such as will keep the pin dry. There should be a considerable distance between the pin and the wire as *a*, in Fig. 18, which gives a sectional view of a petticoat insulator. If the insulator were formed to support the wire at the top instead

of to one side, a greater distance could be obtained between the pin and the conductor. Of course the higher the electromotive force the greater the need of a good insulator.

The material out of which insulators are made is generally either glass or white glazed porcelain. The latter makes the better insulator, and for a high potential it is always used; glass, on account of its cheapness, is used where the conditions allow it.

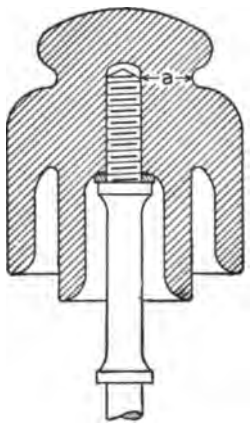


Fig. 18.

Conductors are tied to the insulators with a piece of small wire three or four feet long. The conductor is laid in the groove of the insulator and the binding wire wound several times around the conductor on one side; it is then wound around the insulator and twisted several times around the conductor on the other side, around the insulator again, and finally wound over the conductor on the first side.

As the weight of 100 or more feet of a conductor is considerable, especially if heavily insulated, and as in windy or stormy weather the strain upon them is greatly increased, it is often the case that the size of wire that will satisfy the electrical conditions will not prove strong enough, and a larger size will have to be used. Also for large cables which have any considerable length it is necessary to run a steel rope between the poles, and to hang the conductor from this.

**Jointing.** It it very important in jointing wires or cables that the conductivity of the joint and its mechanical strength should be as great as that of the conductor itself. There should be no free ends left on the finished joint, it should be compact, durable, and if covered wires are used, the insulation should be made continuous and uniform.

A joint as represented in Fig. 19, is very satisfactory for wires less than one-quarter of an inch in diameter. The ends of the two conductors, after having been scraped clean, are laid side by side for a length of about two inches, a short length at each end being bent up at right angles to the axis of the wire. They

are now tightly wound with several turns of a smaller wire, making at first four or five turns on one conductor alone, then over the two, and ending with a few turns on the other wire. Cutting off

Fig. 19.

the protruding ends of wire, soldering into one mass, and smoothing off projections completes the joint, the coating of insulation being then applied if the conductor is a covered one.

A common method of jointing stranded conductors is that known as the **splayed** or **long joint.** The insulation is removed from a few inches of the end of each conductor, all the wires are opened out and the central one cut off short. The ends are then brought together, the wires of one conductor extending between those of the other. The protruding ends are next wrapped closely around the opposite conductor. After trimming, the joint is well soldered, great care being taken in the latter work. Insulation tape is then wrapped closely over the whole.

## UNDERGROUND SYSTEM.

**Conduits.** There are several kinds of underground conduits in use, but the advantages and disadvantages of each have not yet been fully determined.

In the channel system an oblong conduit is built of brick and lined with cement, the bare wires being supported by porcelain insulators at regular intervals. The sides have also been made of cast iron, and notched slabs of porcelain which extend across are used to support the conductors. The collection of moisture in such a channel and consequent corrosion, is a great objection to this system.

A system considerably used on account of its comparative cheapness is that of creosoted wooden ducts. These ducts have a square cross-section, and three inch holes for the cable bored through their centres. The sections are fitted into each other by means of a tapering joint and are laid in a covered wooden box. The creosote is likely to affect the insulation covering of the con-

ductors, also the ducts cannot be run near steam pipes. The conduit is sometimes made of earthenware and has two longitudinal sections each of which receives three ducts.

A system which will give a very good insulation and allow the cables to be withdrawn separately, is that in which blocks of bituminous concrete about six feet in length are used. These have longitudinal circular holes or ways varying from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter, each way receiving one cable. The blocks are jointed by saddle-pieces having two grooves, one on each side of the joint, and these are filled with pitch.

A system having a simple construction is that in which an open box of rough lumber about $1\frac{1}{2}$ inches in thickness is first laid. The cables are laid in this in a filling of pitch, and a cover of creosoted wood is then put on.

Conduits of wrought iron cement-lined pipe, although expensive, have the advantage of being very durable, require but little attention, and allow the conductors to be freely withdrawn and replaced. The pipes have a smooth lining of cement about half an inch thick, and are in lengths of from six to eight feet, threaded at each end. They are jointed by a short piece of pipe threaded on the inside with a right-hand thread at one end, and a left-hand thread at the other. In laying the pipes the trench is first lined with rough lumber. Upon a three-inch layer of cement, pipes are placed one inch apart; then follows a one-inch layer of cement and so on, one pipe being laid for each cable. The top has a three inch layer of cement, and over all is a covering of creosoted wood.

Large iron pipes with a cement interior having several longitudinal ways are sometimes laid directly in the ground.

**Manholes.** In order that a cable may be drawn into a conduit, give a means of inspection, and to allow the replacing of cables, the conduits open into underground compartments or manholes at regular intervals. These are made large enough for a man to work in; they have a thick flooring of cement and twelve inch walls usually of sewer brick. An opening at the top provided with a strong iron cover gives access to the manhole.

In case explosive gases are likely to accumulate in this compartment it is necessary to take special precautions to prevent it. It is often necessary to seal up the cable outlets with some sub-

stance such as plaster of Paris or clay, and to provide ventilating apertures for the manhole.

**Installing Cables.** In installing cables the greatest care must be taken in unrolling and handling them in order not to injure the covering. A number of short rods with threaded ends are used to get the first connection between adjacent manholes. One rod is first placed in the hole to receive the cable. The second length is screwed into this and then pushed in, then a third is added, and so on, a rope being fastened to the last rod. When the first rod appears at the other manhole, it is pulled out and unscrewed, then the second, third, etc., until the rope appears. The cable is attached to the rope, and drawn through by it, being unrolled from a reel placed near the manhole, and carefully guided into the duct.

When obstructions are met with, a piece especially made for clearing the way is pushed through by the rods. If this is not possible, measurements are taken from each manhole to locate the obstruction and the ground reopened at that point.

Underground cables are always lead covered and sometimes have an additional covering for mechanical protection. The joints must always be carefully soldered and finished off so as to allow no moisture to enter the cable. In the manhole the conductors are run quite close to the walls and supported by hooks.

At points where branch circuits lead off from the conduits to buildings or to centres of distribution, there are placed boxes or handholes, provided with apertures for the entrance of the pipes or ducts. In street lighting by the underground system, the conductor leads through a duct to the bottom of the iron pole supporting the lamp, and up through the pole to the lamp.

## WIRING OF BUILDINGS.

Before going into a general description we shall first consider a few terms in common use.

**Switches.** A **jack-knife switch** is, as its name implies, one which opens and closes the circuit by a motion similar to that of the blades of a jack-knife. They are very serviceable and always used for large currents.

**Snap switches** are controlled by turning or pushing a button

and break the circuit by an abrupt motion caused by a spring. They are used for small currents only.

A **service switch** is one placed in the main circuit supplying electricity to a building. It should be placed at the point where the mains enter the building, and should be double-pole, that is, it should open both wires of the circuit when off. This switch should be easily accessible, and indicate plainly whether the current is on or off.

In general, switches should have a firm and secure contact, should make and break abruptly, and have a carrying capacity sufficient to prevent heating above the surrounding atmosphere. They should be mounted on moisture-proof and non-combustible bases, such as slate or porcelain, and should be placed in a dry place.

**Fuses.** A fuse is a wire or strip made of some easily fusible material, and is placed in the circuit for protection from large or dangerous currents. The carrying capacity is determined by the diameter or cross-section of the wire, and should an excessive current pass through the fuse it is heated and melts, breaking the circuit. They are usually stamped or marked with the number of amperes they will carry indefinitely without melting.

**Cut-outs.** Cut-outs are boxes or receptacles for the fuses made of material which is moisture-proof and non-combustible. They are usually made of porcelain or slate with a removable cover, have places for the conductors to be attached, and a space for the fuse to connect across. The fuses should be tipped with copper contact pieces.

A **plug cut-out** is a plug containing a fuse and arranged to be inserted into the circuit when the plug is screwed into or fixed in its socket.

A **cut-out block** or **fuse block**, is simply a block of proper material upon which the fuse may be mounted.

Cut-outs should be placed where the mains enter the building, and at every point where a change is made in the size of the wire.

A **cut-out cabinet** is a box in which several cut-outs may be located, being a local centre of distribution. This protects the cut-outs from dust and dirt as well as concealing them. The

cabinet should have two coats of shellac inside, should be lined with asbestos, and the door should be as large as the cabinet will permit.

**Arrangement.** It is of course desirable that the potential used in wiring buildings should be low, which requires the use of the parallel system. In wiring a building it is customary to run mains to centres of distribution or to cut-out cabinets, and from these to run the lamp circuits. It is not a good policy to have more than ten 16 c. p. lamps on a circuit, and no wire smaller than No. 16 B. & S., or better, No. 14, should be used.

For a small building the lamp circuits can run directly from the point where the mains enter the building, or from one centre. Large buildings require several centres, their number and location depending upon the number of lamps and upon their distribution. It might be sufficient to run the leads up near the centre of the building to cut-out cabinets located on each floor, each cabinet being supplied with independent leads. For a long, narrow building it might be necessary to run two sets of leads up, one near each end.

**Exposed Wiring.** Where the appearance of wires is of but little consequence, exposed wiring is, on account of its cheapness and accessibility, much to be preferred. The conductors are supported if large, by being tied with small wires to porcelain **knobs** attached to the wall or ceiling by screws through their centres. Smaller conductors are supported by **cleats.** These may be single, double, or triple, as for the three-wire system. Fig. 20 shows a double cleat, that is, for two wires. They are usually made of porcelain and in two parts to allow the wire to be inserted. They should not be placed more than four feet apart and screws should always be used in fastening them to the walls or ceiling. Cleat-work is not permissible except in a very dry place and where it is open for inspection at any time. For 150 volts or less the distance between wires should be at least two and one-half inches.

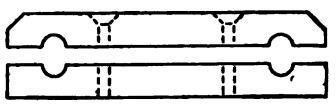


Fig. 20.

Whenever conductors cross metallic pipes or any conducting material, they should be separated therefrom by at least one inch

of some continuous non-conductor; in crossing high potential conductors there should be at least six inches. In wet places an air space should be left between the conductors and pipes, and conductors should run *above* pipes upon which condensed moisture is likely to gather, or which are likely to drip. In passing through floors, walls, timbers, etc., conductors should be protected by insulating tubes, such as glass or porcelain.

**Wiring in Moulding.** A method of wiring very much used is that where the wires are concealed in moulding which may be of a design to correspond with the moulding around the room. The moulding carries two or more wires as desired, each having its separate wire-way. It is made in two parts; one part containing the wire-ways is first fastened up, the wires then put in their position, and the outside covering is next screwed on. Fig. 21 shows a cross-section of a wall moulding for two wires. Mouldings are not to be used in damp places, should not have open grooves against the wall or ceiling, and should be coated twice with water-proof paint.

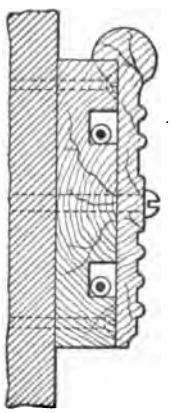


Fig. 21.

**Interior Conduits.** The most approved form of wiring and one in which the wires and their raceways are entirely concealed is the interior conduit system. The conduits are tubes of insulating and non-combustible material extending between walls and between floors and ceilings; they are installed during the construction of the building and are continuous from cabinet to cabinet, from cabinet to outlet, and from outlet to outlet. In order to give mechanical protection from saws, chisels or nails, the tube should be of a substantial character and for this reason tubes of iron, brass, or steel, having a lining of insulating material are used. Two separate conductors or a twin conductor are often run in the same tube.

The tubes are first installed as a complete conduit system, the conductors being drawn into them after the construction work on the building has been completed. To insert the conductors a **fishing wire** is first pushed through the tube, the conductor is attached to this and then drawn into place. To facilitate this work

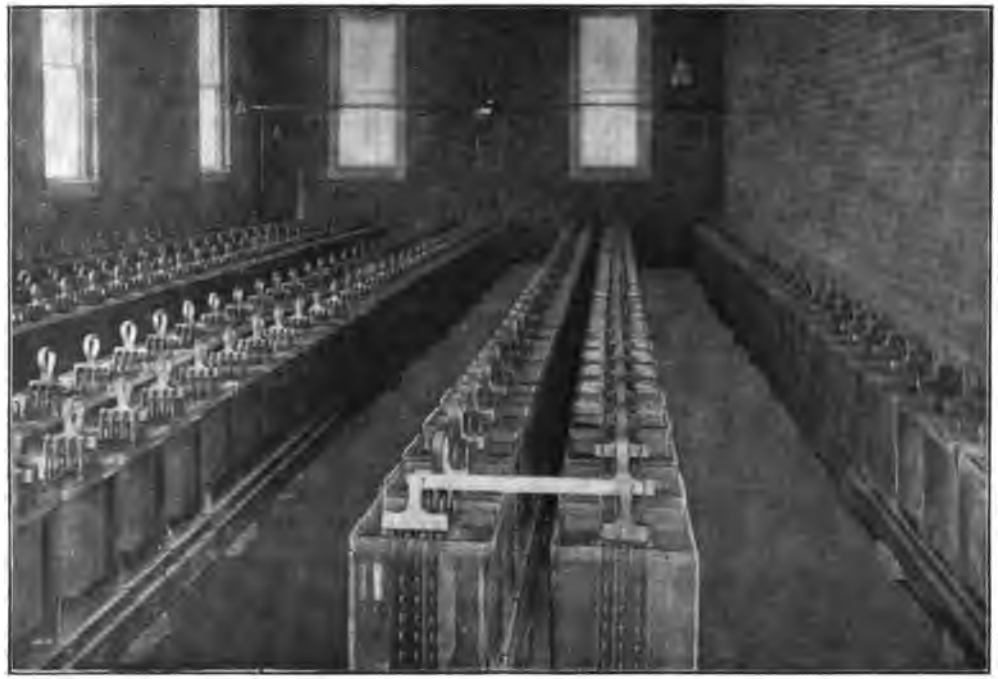
powdered soapstone should first be blown into the tube. Burrs formed in cutting off the ends of tubes should be carefully removed to prevent the wires from catching and to prevent any damage to their insulation.

## CALCULATIONS FOR SIZE OF WIRE.

Knowing the amount of electrical energy to be supplied to any point or points, it remains to be determined what size of wire will be required to transmit this over the required distance. In deciding upon this two things must be considered; the **loss of energy** or allowable drop, and the **safe carrying capacity** of the conductor, that is, the amount of current which can be carried without excessive heating. The method to be followed is to first calculate the size allowing a certain loss, and then if the current is not above the safe carrying capacity of the wire this size is used, otherwise a larger wire is necessary.

The following table gives the safe carrying capacity of insulated wire allowing 10° C., or 18° F. rise above the surrounding air, also the resistance per 1,000 ft. of copper of 97% conductivity at 75° F.

| Size B. & S. Gauge. | Safe Carrying Capacity. | Circular Mils. | Resistance 97 per cent Conductivity. Ohms per 1,000 feet. |
|---|---|---|---|
| 0000 | 175 | 211600 | .05129 |
| 000 | 145 | 167800 | .06467 |
| 00 | 120 | 133100 | .08155 |
| 0 | 100 | 105600 | .1027 |
| 1 | 85 | 83690 | .1297 |
| 2 | 70 | 66370 | .1635 |
| 3 | 60 | 52630 | .2062 |
| 4 | 50 | 41740 | .2599 |
| 5 | 45 | 33100 | .3279 |
| 6 | 35 | 26250 | .4134 |
| 7 | 30 | 20820 | .5213 |
| 8 | 25 | 16510 | .6574 |
| 9 | 22 | 13090 | .8288 |
| 10 | 20 | 10380 | 1.045 |
| 12 | 15 | 6530 | 1.662 |
| 14 | 10 | 4107 | 2.642 |
| 16 | 5 | 2583 | 4.201 |
| 18 | 3 | 1624 | 6.683 |



**CAMDEN INTERSTATE RAILWAY'S ELECTRIC STORAGE BATTERY PLANT AT IRONTON, OHIO.**
(By courtesy of the Electric Storage Battery Company.)

A simple method of obtaining the proper size of wire is to calculate the resistance per foot that is permissible, and then, assuming we have copper of 97% conductivity, by referring to the table we find the size corresponding.

Since resistance equals the electromotive force divided by the current if we know the current, the drop in volts, and the length of the circuit, the resistance per foot may be obtained. The length of the circuit is of course twice the distance from the source to the centre of distribution.

Hence from Ohm's law we have the general formula,

$$L\,R = \frac{D}{I}$$

$$\text{or } R = \frac{D}{I \times L}$$

where $R$ represents the resistance per foot, $D$ the allowable drop in volts, $I$ the current, and $L$ the length of the circuit.

Example. — It is desired to transmit a current of 80 amperes through a circuit to be 300 feet in length allowing a drop of 2.5 volts. What is the size of wire required?

Solution. — Here $D = 2.5$ volts, $I = 80$ amperes, and $L = 300$ feet.

Therefore

$$R = \frac{2.5}{80 \times 300}$$

$$= .000104 +, \text{ or } .104 \text{ ohms per } 1000 \text{ feet.}$$

From the table on page 48, we see that this resistance corresponds very closely with No. 0 wire, and since the resistance of No. 0 wire is less per thousand feet, and the carrying capacity greater than 80 amperes, this size is the one required.

Ans. No. 0 B. & S.

Example.— A No. 6 B. & S. wire 98 feet long carries a current of 22 amperes. What is the drop in volts?

Solution.— Transposing $I$ in the general formula

$$L\,R = \frac{D}{I}$$

we obtain

$$L\,R\,I = D$$

In this case $L = 98$ feet, $I = 22$ amperes and $R = 0.4134$ ohm per 1,000 feet, or 0.0004134 ohm per foot.

Therefore, $D = 98 \times 0.0004134 \times 22 = 0.8913$ volt.

The above formula is usually expressed in slightly different values for incandescent lighting circuits. In place of the length of the circuit is put the distance between points where the drop occurs, or one-half the length of the circuit, and the current is replaced by the number of 16 c. p. lamps used, or if other lamps are used, their equivalent in 16 c. p. Since at 110 volts a 16 c. p. lamp takes about .5 ampere, the number of such lamps supplied at that voltage will be twice the number of amperes required.

Hence if $N$ represents the number of 16 c. p. lamps on the circuit, and $F$ the distance between points where drop occurs, then this formula for a **110 volt circuit** and **16 c. p. lamps** becomes,

$$R = \frac{D}{\frac{N}{2} \times 2F} = \frac{D}{N \times F}.$$

The following table gives the average current taken by lamps of different candle power at 110 volts and at 55 volts.

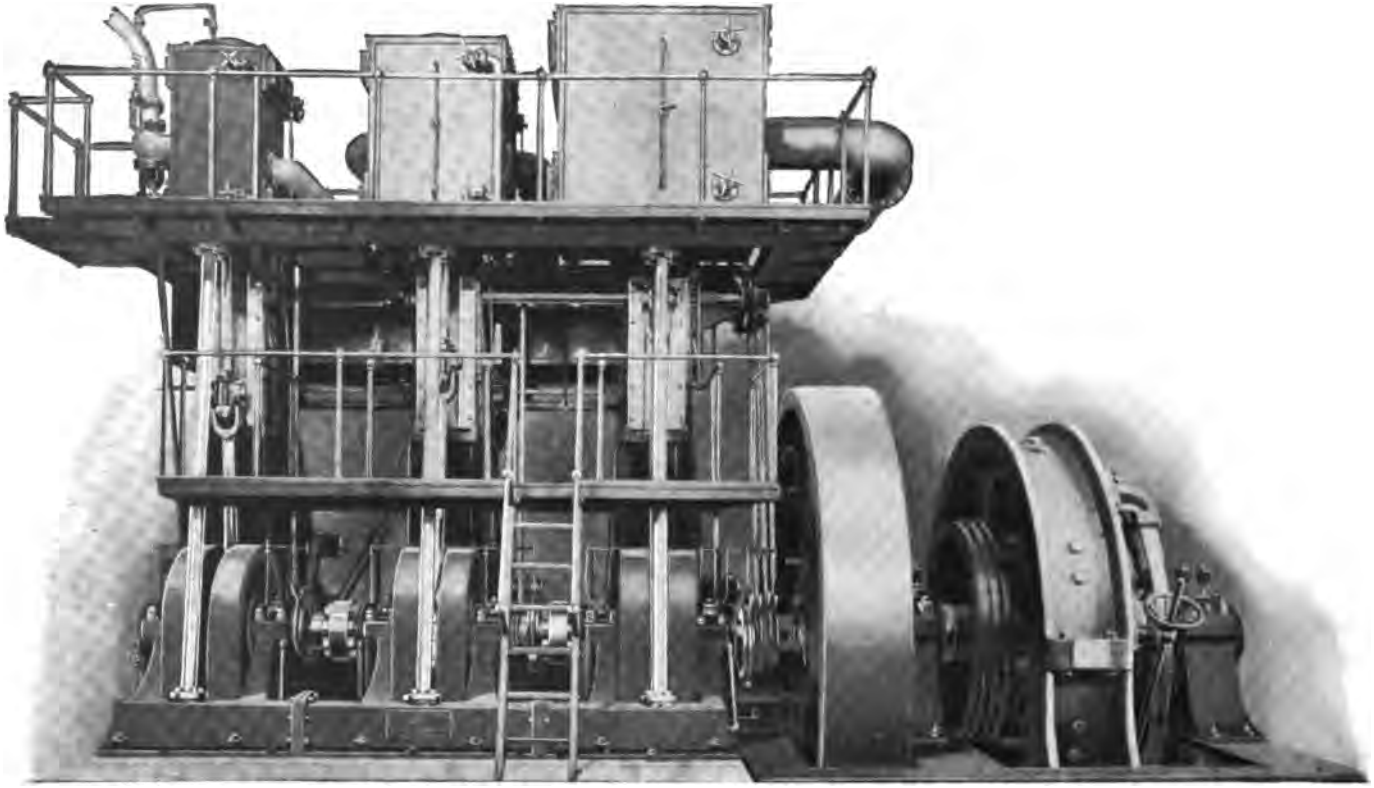
| C. P. | At 110 Volts. | At 55 Volts. |
|---|---|---|
| 16 | .5 | 1. |
| 32 | 1.0 | 2. |
| 50 | 1.5 | 3. |
| 100 | 3.0 | 6. |

Example.—There are six 16 c. p. and two 32 c. p. lamps on a 110 volt circuit. The distance between the source and the centre of distribution is 30 feet and a drop of 1.0 volt is allowed. What size of wire is necessary?

Solution. — Two 32 c. p. lamps take as much current as four 16 c. p. Adding this to six, we have $N = 10$; also $D = 1.0$, and $F = 30$. Therefore,

$$R = \frac{1.0}{10 \times 30} = .0033 + \text{ or } 3.3 \text{ ohms per } 1000 \text{ feet.}$$

From the table on page 48, we see that this resistance comes between No. 14 and No. 16 wire, hence we must take the



**850 HORSE-POWER VERTICAL TRIPLE-EXPANSION ENGINE, WITH A DIRECT-CONNECTED GENERATOR.**
(Courtesy of McIntosh, Seymour & Company.)

larger size, and this also has a safe carrying capacity for the current which would be 5. amperes. Ans. No. 14 B. & S.

In case the voltage is 55, the current will be twice as great for lamps of the same c. p. as when it is 110. Hence the preceding formula becomes, for a **55 volt circuit** and **16 c. p. lamps,**

$$R = \frac{D}{2NF}.$$

Example. — What size of wire should be used to supply sixty 55 volt lamps of 32 c. p. at a distance of 120 feet from the dynamo, a drop of 2 volts being allowed?

Solution.— Sixty lamps of 32 c. p. take as much current as 120 lamps of 16 c. p., hence $N = 120$.

Substituting in preceding formula,

$$R = \frac{2}{2 \times 120 \times 120} = .00007 \text{ ohm nearly.}$$

This resistance comes between that of No. 00 and No. 000 wire, hence we take No. 000, and this safely carries the current.

Ans. No. 000 B. & S.

Example.— What size of wire should be used to supply 12 lamps of 50 c. p., 18 of 32 c. p. and 70 of 16 c. p., all of 55 volts and at a distance of 110 feet?

Solution.— Twelve lamps of 50 c. p. take as much current as $12 \times 1.5 = 18$ lamps of 16 c. p. Eighteen lamps of 32 c. p. are equivalent to 36 lamps of 16 c. p. The total equivalent of 16 c. p. lamps is, therefore,

$$18 + 36 + 70 = 124 \text{ 16 c. p. lamps.}$$

Hence $N = 124$.

Therefore, since $N = 124$, $D = 2$ and $F = 110$, we have

$$R = \frac{2}{2 \times 124 \times 110} = 0.000073 \text{ ohm.}$$

Therefore, as in the preceding example, No. 000 B. & S. should be used.

The two preceding formulas are based on a current consumption which gives an efficiency of about 3.5 watts per candle. This is a fair average for good lamps.

A method by which the **size of the wire may be computed directly in circular mils** is convenient, especially for large wires.

This method is based upon the fact (see page 38) that the resistance of 1 foot of ordinary copper wire having a cross-section of 1 circular mil is, at 68° F., 10.3 ohms. Since impure copper has a higher resistance than pure copper, and as increase of temperature causes increase of resistance, it may be assumed in computing the size of wire that this resistance is 11 ohms.

As the resistance varies directly as the length of circuit, and inversely as the area, we have,

$$R = \frac{11 \times L}{C.M.}$$

or for the circular mils we have,

$$C.M. = \frac{11 \times L}{R}$$

but as the resistance equals electromotive force divided by the current,

$$C.M. = \frac{11 \times L}{\frac{D}{I}}$$

$$= \frac{11 \times L \times I}{D}$$

where $L$ is the length of the circuit in feet, $I$ the current, and $D$ the drop. This may be used as a **general** formula.

Example.—What must be the size of the conductor to transmit a current of 60 amperes through a circuit 400 ft. in length with a drop of 2 volts?

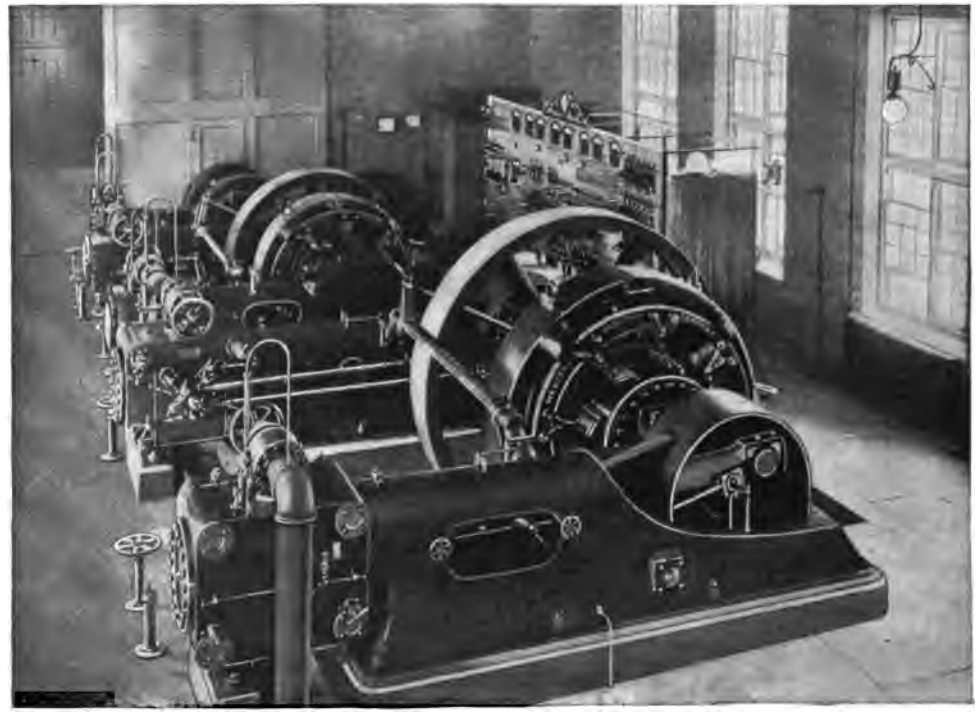
Solution.—

$$C.M. = \frac{11 \times 400 \times 60}{2} = 132{,}000.$$

From the table the next larger size is No. 00, and this will carry the current safely. Ans. No. 00 B. & S.

For **110 volt circuit** the formula, when expressed in number $N$ of **16 c. p. lamps** and distance $F$ between points where drop $D$ occurs, becomes

$$C.M. = \frac{11 \times N \times F}{D}.$$



ENGINE ROOM AT THE UNIVERSITY OF CHICAGO, SHOWING ONE 350 K. W., ONE 250 K. W., ONE 100 K. W. COMPENSATOR SET AND SWITCHBOARD.

(By Courtesy of Western Electric Company.)

Example.— What size of wire must be run from a cut-out to 10 110 volt lamps of 16 c. p. at a distance of 50 feet, allowing a drop of 1 volt?

Solution.— In this case $N = 10$ lamps, $F = 50$ feet, $D = 1$ volt.

Therefore,

$$C.M. = \frac{11 \times 10 \times 50}{1} = 5{,}500.$$

This falls between No. 12 and No. 14, and No. 12 would be selected.

For a **55 volt circuit** and **16 c. p. lamps,** the formula should be

$$C.M. = \frac{2 \times 11 \times N \times F}{D}.$$

Example.— The mains of a 55 volt circuit are to run a distance of 186 feet, supplying at the distant points 24 lamps of 16 c. p., and 20 lamps of 32 c. p. If the drop is 2 volts, what should be the size of the mains?

Solution.— Twenty lamps of 32 c. p. are equivalent to 40 of 16 c. p., and in this case the total equivalent of 16 c. p. lamps will be $40 + 24 = 64$ lamps.

Therefore, $N = 64$ lamps, $F = 186$ feet, $D = 2$ volts.

Hence, $C.M. = \frac{2 \times 11 \times 64 \times 186}{2} = 130{,}944.$

Ans. No. 00 B. & S. should be used.

In any of the preceding formulas, if all but one of the quantities are known, the other may be easily found.

Example.— What current can be carried by a No. 4 B. & S. wire 100 feet long, with a drop of 0.65 volt?

Solution.—

$$\text{Since } C.M. = \frac{11 \times L \times I}{D}$$

$$\text{then } I = \frac{D \times C.M.}{11\,L}$$

$$= \frac{0.65 \times 41{,}740}{11 \times 100} = 27.13.$$

Ans. 27.13 amperes.

The percentage drop allowed is sometimes given, and this percentage always applies to the supply available at the source.

Example.—There are forty 110 volt incandescent lamps of 16 c. p. to be supplied allowing a percentage loss of 2. The distance from dynamo to centre of distribution is 60 ft. What is the necessary size of wire?

Solution.—As the voltage at the lamp terminals must be 110, the voltage of the dynamo $= \frac{100}{98} \times 110 = 112.24+$

$$\text{drop} = 112.24 - 110 = 2.24+$$

$$C.\ M. = \frac{11 \times 40 \times 60}{2.24}$$

$$= 11800. \text{ (approx.)}$$

From the table on page 48 we see that No. 9 must be used, and that this safely carries 20 amperes. Ans. No. 9 B. & S.

Example.—There are 100 lamps of 32 c. p. and 110 volts to be supplied by mains which run a distance of 85 ft. A percentage drop of 3 is allowed, what must be the size of the mains?

Solution.—Voltage of dynamo $= 110 \times \frac{100}{97} = 113.4+$

$$\text{drop} = 113.4 - 110 = 3.4 \text{ volts.}$$

$$C.\ M. = \frac{11 \times 200 \times 85}{3.4}$$

$$= 55{,}000.$$

From the table it is evident that No. 2 wire would be large enough as far as loss of voltage is concerned, but it cannot safely carry 100 amperes. Hence we must use No. 0 wire.

Ans. No. 0 B. & S.

Example.—In the preceding example what will the drop be if No. 0 wire is used? What must be the voltage of the dynamo?

Solution.—*C. M.* of No. 0 wire $= 105600.$

$$105600 = \frac{11 \times 200 \times 85}{D}$$

$$D = \frac{11 \times 200 \times 85}{105600}$$

$$= 1.77+ \text{ volts.}$$

$$\text{Voltage of dynamo} = 110 + 1.77+$$

$$= 111.77+ \text{ volts.}$$

Ans. $\begin{cases} 1.77+ \text{ volts.} \\ 111.77+ \text{ volts.} \end{cases}$

**Calculations for Three-wire System.** In calculating the size of wire for the three-wire system the neutral wire may be neglected because for a well-balanced system the current in this is small. It may be considered then, as a two-wire system having double the voltage. If the voltage is doubled the current required to transmit the same amount of electrical energy will be only half as great. Thus if we have four 110 volt 16 c. p. incandescent lamps, two on each side of the neutral wire, the current in the outside wires will be but one ampere. As the drop depends only upon the current and resistance, it is evident that this will be one-half of that which would occur in case the lamps were on a two-wire 110 volt circuit.

Hence we have the **general** formula,

$$R = \frac{D}{I \times L}$$

where $R$ is the resistance per foot, $I$ the current in the outside wires, $L$ the length of the two outside conductors in feet and $D$ the drop.

Also the formula,

$$R = \frac{2D}{N \times F}$$

where $R$ is the resistance per foot, $N$ the number of **16 c. p. 110 volt lamps** on both sides of the circuit, $F$ the distance between points where the drop occurs, and $D$ the drop.

In circular mils we have the **general** formula,

$$C.\ M. = \frac{11 \times L \times I}{D}$$

where $L$ is the length of the two outside wires, $I$ their current, and $D$ the drop.

Also,

$$C.\ M. = \frac{11 \times N \times F}{2 \times D}$$

$$= \frac{5.5 \times N \times F}{D}$$

where $D$ is the drop, $N$ the number of **16 c. p. 110 volt lamps** on both sides of the circuit, and $F$ the distance between points where the drop occurs.

Although the current in the neutral wire is generally small, it is very variable and may sometimes be quite large, and it is the usual practice to make this of the same size as the outside conductors.

In using any of the above formulas it must always be remembered that distance or length of circuit must be expressed in feet.

**Amount of Copper in Three-wire System.** We have seen that in transmitting a certain amount of electrical energy over a certain distance that if the voltage is doubled, the current is reduced one half. As the loss of energy is equal to the square of the current multiplied by the resistance, the loss with twice the voltage is only one-fourth if the same resistance is used; or, for an equal loss, the resistance could be four times as great, that is, the cross-section of the wire could be reduced one-fourth if the voltage is doubled. Hence with the same percentage loss of energy, or with the same percentage drop, the amount of copper used in the three-wire system will be $\frac{3}{8}$ of that required by the two-wire system, for the outside wires require but $\frac{1}{4}$ as much, and if the neutral is the same size it will require an additional $\frac{1}{8}$ as it is only half the length of the circuit, making $\frac{3}{8}$ in all.

In wiring a building on the three-wire system, the three wires are usually run to the different cut-out cabinets, and from these run two-wire lamp circuits.

Example.—Three-wire mains are to extend from a switch-board to a cut-out cabinet at a distance of 200 ft., from which 80 lamps of 16 c. p. and 110 volts are to be supplied. The drop allowed in the mains is 1.5 volts, what size of wire is required?

Solution.—By using formula $C.M. = \frac{5.5 \times N \times F}{D}$ we have,

$$C.M. = \frac{5.5 \times 80 \times 200}{1.5} = 58666.+$$

By reference to the table we see that No. 2 wire must be used, and this will safely carry the current of 20 amperes.

Ans. No. 2 B. & S.

In general the percentage drop in mains for incandescent lighting varies between 1 per cent and 3 per cent. A drop larger than $2\frac{1}{2}$ per cent usually causes considerable fluctuations in the brilliancy of the lamps. A very small drop is highly desirable for good regulation, but it cannot economically be made less than about

1 per cent, except for very short lines, on account of the cost of the copper involved. To reduce a given drop one-half, requires just double the weight of copper.

**Planning the Wiring.** In laying out an installation care should be taken to avoid pipes, damp places, crossing of wires, and any complicated or unnecessary wiring, as far as possible. The main switches and cut-outs should be grouped together and located in safe and easily accessible places.

The general method to be followed in planning the wiring for a building is to first indicate upon the plans the position and number of lamps necessary and the location of the snap switches if any are to be used. After a consideration of the location and number of lamps, and the convenience of places for running the mains and for locating the cut-out cabinets, the lamps are divided into groups, each group being supplied from one cut-out cabinet. There may be one or several groups of cut-outs on each floor.

The lamp circuits are then planned to run from the cut-outs, arranging as nearly as possible ten 16 c. p. lamps, or the equivalent, on each circuit.

The mains from the switchboard are now planned to run to the cut-out cabinets, one set of mains to each or to several, depending upon the number of lamps supplied by each or how closely situated. It is desirable to have the load on the mains about equally distributed. Places in a building in which the mains may run are usually limited, and the cut-out cabinets must of course be located where no difficulty will be had in running the mains to them. There should be in a building one or more wire-ways or conduits especially provided for the running of the mains through the building.

The drop to be allowed in different parts of the wiring system depends upon the length of their circuits and their current. In street mains and feeders the drop is usually considerable, and in large buildings from 4% to 6% often occurs, being divided up between the main conductors and lamp circuits.

In determining the size of wire it is only necessary to count up the number of lamps supplied by a conductor, and either obtain the equivalent number of 16 c. p. lamps, using the formula for 110

volt or 55 volt circuits, as the case may be, or else to determine the current required and use the general formula. The distance between points where drop occurs is found by spacing it off from the plans, following the turns of the circuit from the source of supply to the centre of gravity or centre of distribution of the lamps supplied. The length of the circuit, as used in the general formula, is to be taken as twice this distance. Having found the number of lamps supplied, or the current, the distance between points where drop occurs, and having allowed a certain drop, the size of the wire can then be found.

**The Nernst Incandescent Lamp.** This lamp, the invention of Dr. Walther Nernst, has recently been put upon the market in America. The light-giving element, instead of being a thread of carbon, as in the ordinary incandescent lamp, is a rod of porcelain, or *glower*, about $\frac{1}{32}$ inch in diameter and 1 inch long. The current passing through it heats it to a very high temperature, producing a brilliant light of a fine white color. The glower is fastened to the holder by small platinum wires and aluminum plugs. Lamps now made have from one to six glowers, each taking 0.4 ampere at 220 volts.

The glower is a non-conductor of electricity when cold, and to start the lamp a *heater* is necessary to bring the glower up to a red heat. The heater consists of two or more white porcelain tubes, about as large as a lead-pencil. These are wound with fine platinum wire, and then covered with a refractory paste, which serves to protect the heater from the intense heat of the glower when in operation.

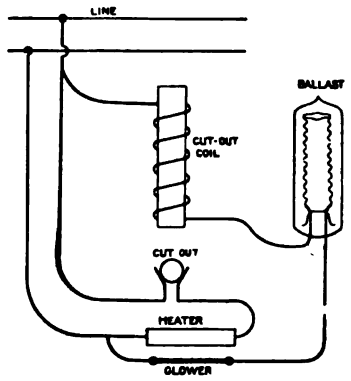



Fig. 22.

The resistance of the glower decreases rapidly as the temperature rises, and as the lamps are run from constant potential mains, the increase of current would overheat and destroy the glower, if unchecked. A steadying resistance, or *ballast*, is therefore put in series with each glower, acting very

much like the resistance used in constant potential arc lamps. It is made of fine iron wire, enclosed in a glass tube.

The arrangement of the various parts is shown in Fig. 22. The heater and glower are in parallel across the mains. When the switch is closed, the current at first can pass only through the heater circuit, since the high resistance of the glower permits practically no flow through it. In about half a minute the heater raises the glower to a red heat, and at about this point the resistance is reduced enough to allow current to pass through the glower, which instantly comes to brilliant incandescence.

The heater is now unnecessary, and is cut out by the *cut-out coil.* This is simply an electro-magnet in series with the glower, and whose armature forms a part of the heater circuit. When the current passes through the glower and the magnet coil, the armature is lifted, thus breaking the heater circuit.

The energy consumption is about 88 watts per glower. The life of the glower is stated to be about 800 hours, and that of the heater about 2,500 hours. The lamps are made only for alternating current circuits from 200 to 240 volts.

BATTERY ROOM ARCH STREET STATION PHILADELPHIA ELECTRIC COMPANY.
(By Courtesy of the Electric Storage Battery Company.)

## SECTION 4.

# ELECTRIC RAILWAYS.

Previous to the year 1883 electricity had not been applied to the operation of railways. By 1889 the success of the overhead or trolley system had been fully demonstrated, and from that year dates the rapid introduction of electric railways. Up to the year 1900 electric cars were run on nearly 18,000 miles of track, and over 50,000 cars had been electrically equipped in the United States alone.

As the overhead system has given the best results and has been universally adopted, we will first consider this system in detail.

Fig. 1 illustrates the electrical circuit in this system. The current passes from the generator to the line, which is generally positive, then by the trolley through the car motors and connections to ground. The return circuit is formed by the rails; con-

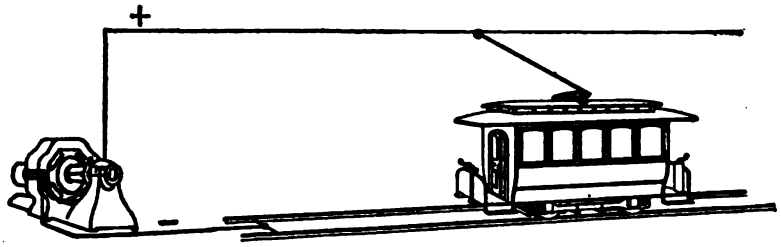



Fig. 1.

nection being made between them and the negative terminal of the generator. Each car is usually provided with two motors and in circuit with them are the controllers, one on each platform, for governing the speed of the car. There is a starting resistance; also fuses, switches, and lightning arrester. The heating and lighting circuits are independent. Connection to ground or to rails is made through the car axles and wheels.

The car may be run in either direction by making a change in the motor connections. The voltage of the line is kept constant at about 500 volts. The cars are connected in parallel between the line and the rails; an increase in the number of cars operated causing the line current to be greater.

## CAR EQUIPMENT.

**Trucks.** The ordinary street car is composed of two distinct parts: the *car-body*, or framework arranged for the convenience of passengers, and the *car truck*, or the part upon which the car body rests.

There are the following three general methods of supporting a car body.

1. By a single rigid truck, having four wheels and two axles, the axles remaining very nearly parallel, in all positions of the car, whether on straight track or on a curve. This truck is more often used on short cars.

2. By the use of two four-wheel trucks, the swivel centres of which support the car, one being placed at each end of the car.

3. By the use of three trucks, the car being supported by the two end trucks. The middle truck is capable of a side motion so that the axles are only parallel on a straight track and radial when rounding a curve.

A single truck is shown in Fig. 2. The car is supported upon the long side frames, which in turn are supported by the spiral

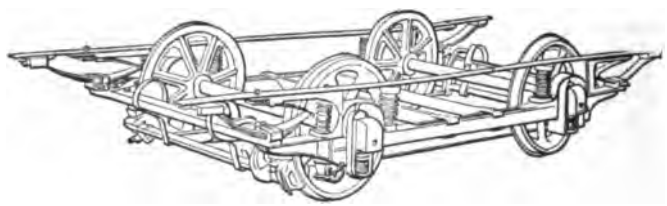


Fig. 2.

springs near the journal boxes. For short cars the spiral springs are sometimes the only ones provided, but usually there are also elliptical springs as shown at the end of the side frames. These provide a longer spring base which greatly diminishes oscillation of the car body. This oscillation has a very destructive effect on the car body, causes hammering on the tracks, and diminishes the tractive force of the wheels by causing them to slip. To diminish this the elliptical springs are placed at the extreme end of the truck frame. The *wheel base*, that is, the perpendicular distance between the centre lines of the axles, is usually six feet six inches in this form of truck and should not be greater than seven feet.

As the wheel base increases in length the force required to propel a car around a curve increases proportionally. The wear and tear of the track and car wheels also becomes greater.

Trucks for double truck cars are sometimes arranged so that the greater part of the weight of the car is supported by two pair of wheels, that is, the points of support on the trucks are nearer one axle than the other. The motors are geared to the axles supporting the greater loads. Another form of truck for the double truck car, known as the *maximum traction truck*, has two axles and two pair of wheels of different diameters. The motor is suspended in such a manner as to drive the larger pair of wheels. The maximum traction effort is obtained by supporting the car body so that nine-tenths of the weight of the car is carried by the driving wheels. The majority of large cars having double trucks, however, are supported upon pivots in such a manner that the total weight of the cars is distributed equally on the eight wheels. The pivot is then in the centre of the truck.

The Robinson Radial Truck, shown in Fig. 3, is an example of the third type of truck. In this type the car is supported

Fig. 3.

almost entirely on the centres of the end trucks. These are provided with rollers which bear against plates on the under side of the car frame, allowing the trucks to readily adjust themselves to any required position. The motors are arranged to drive the end wheels. The centre truck is free to move transversely with respect to the car, and is guided by side rollers bearing against cross beams on the car frame. It is of light construction with small wheels, and its function is to direct the other trucks and keep them tangent to the track when rounding a curve. This type of truck has a very long wheel base which prevents oscillations of the car body. It is capable of rounding a curve of comparatively small radius as easily as if it were on a straight track.

**Car Wheels.** The wheels used in electric street car work, weigh from 300 to 400 pounds each and are generally 30, 33,

or 36 inches in diameter. The running face, or *tread* as it is called, is usually chilled to a depth of from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch. This increases its life and improves its wearing qualities. Good wheels should run at least 30,000 miles before being discarded. The wheel is usually attached to its axle by forcing it on under hydraulic pressure. In some cases the wheels are bolted to collars which have previously been forced upon the axle.

**Motor Suspensions.** As the weight of the ordinary street car motor is very nearly a ton, it is necessary to support it by a spring suspension. The hammer action which would otherwise take place between the car wheel and the track, is thus avoided. There is still the dead weight of the car wheels and axles to produce the action, but this is not great if the weight of the motor is not added.

There are two methods of suspension in common use, the *nose* or *wheelbarrow* method, and the *parallel side-bar* method.

In the nose suspension an end view of which is shown in Fig. 4, one end of the motor *M* is rigidly attached to the car axle *A*. The end of the motor farthest from the axle is supported by a cross bar *C*, which is parallel with the car axle. The ends of this bar are supported upon the truck frame by powerful springs. The only movement possible for the motor is in the arc of a circle with the car axle as a centre; the motor gear is therefore always in mesh with that on the car axle. By this method the motor may be suspended from its top frame, enabling the lower half to be swung down when making repairs. This gives easy access to it without disturbing the upper frame which remains suspended from the axle and suspension bar.

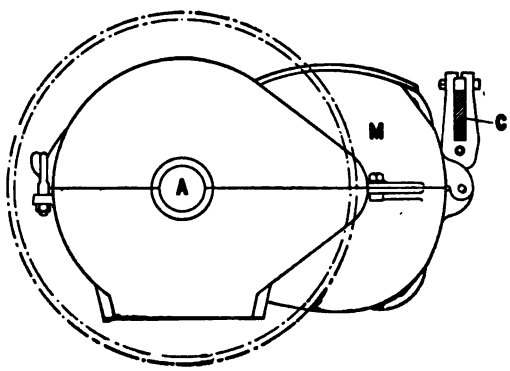


Fig. 4.

In the side-bar suspension the weight of the motor is entirely removed from the car axle. The motor is carried by two parallel

bars, one on each side, and is supported in the line of its centre of gravity. These bars are supported by the truck through spiral springs.

**Brakes.** In running cars through crowded thoroughfares, it is of great importance that the brake shall operate to bring the car to a complete standstill with absolute certainty and within a very short distance. Various forms of brake mechanism, operated by hand, by electric current, or by pneumatic pressure have been devised to accomplish this purpose.

Compressed air has been used to some extent for electric locomotive work. At the present time, however, it is rapidly coming into use for the heavy electric cars of suburban lines.

A common form of *lever brake*, which may be operated from either end of the car, is shown in Fig. 5. The rotation of the

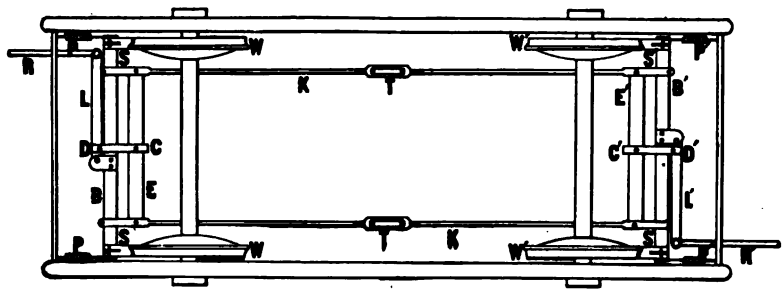



Fig. 5.

brake handle causes a chain to be wound around the handle shaft, and the power is applied to the brake shoes $SS'$. Suppose the brake to be operated at the left-hand end. The chain connects with the rod $R$, which is attached to the lever $L$. This lever is attached to the brake beam $B$, and also to the cross-piece $E$. The lever may be considered pivoted at $D$, and a pull on $R$ will force the shoes $S$ against the wheels $W$. A direct pull is then transmitted to the bar $E$ and through the rods $K$, to the brake beam $B'$ at the other end of the car. By this means all four brake shoes are applied simultaneously with equal force. The turn buckles $T$ enable excessive slack to be taken up, so that the brakes may be quickly applied. The springs $P\,P'$ serve to keep the brake shoes away from the wheels when not in use.

When power is applied to the brake handle this pull is first

increased by the leverage of the handle, and then further multiplied by the leverage of the lever arm $L$. Suppose a pull of 128 pounds is exerted upon the handle; let us find the retarding drag that would be transmitted to the wheel tread. Assuming the combined multiplying power of the levers as 50, and that only $\frac{1}{8}$ of the pressure delivered by the brake shoe acts as a retarding force, we have:

Total pressure at the brake shoes

$$128 \times 50 = 6{,}400 \text{ pounds.}$$

Brake pressure on each wheel

$$6{,}400 \div 4 = 1{,}600 \text{ pounds.}$$

Retarding force at each wheel

$$1{,}600 \div 8 = 200 \text{ pounds.}$$

Hence for 128 pounds pressure applied to the brake handle, we have a drag of 200 pounds applied to each wheel.

Among the many methods that have been devised to stop a car by means of electrical power there are those using storage batteries, the line current, and the motor as a generator.

The first of these has not yet come into practical use on account of the expense of maintenance, and of recharging. Also the first cost of such a battery is considerable.

The second method, depending upon the line current, is not very reliable, because of the fact that it becomes inoperative if the trolley should happen to slip off or the line current fail entirely. The possibility of such an occurrence renders this system of little value.

By the third method the motor itself is made to stop the car. In this case the motor acts as a generator, the line current being switched off. The current thus generated, due to the momentum of the car, is led through a low resistance and the motor thereby short circuited. This heavy load on the motor soon brings it to rest. This system has the advantage that it is self-contained, and does not depend upon the line current. It has, however, the disadvantage of being very severe on the motor and gearing. If the resistance in the armature circuit is cut out too suddenly, there is some danger of stripping the pinion on the motor shaft.

By far the best electrical brake that has been devised, and one which promises to come into extended use is represented in

Fig. 6. This brake is usually applied to the truck in addition to the ordinary hand brake mechanism. The brake is composed of two parts, the iron disk *A*, which is firmly keyed to the car wheel axle *C*, and a stationary circular shoe or electromagnet *B*. This faces *A* and is supported by the motor frame. When it is desired to stop the car the line current is switched off, and the motors which are still running, act as generators. The current generated is led through the coil *D* in an annular space of the piece *B*. A strong magnetic field is consequently produced, the path of the magnetic flux being indicated by the dotted lines. The motion of the disk *A* in the magnetic field causes the production of eddy currents in it, which act to oppose the rotation and to bring the car to rest.

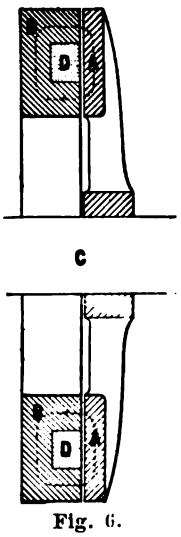


Fig. 6.

The faster the car is moving, the stronger will be the current generated by the motors, the greater will be the electromagnetic eddy current action, and consequently the higher the brake action on the wheels.

The brake is under the control of the motor-man, the current generated by the motors passing through the controller, to be later described, and applied to the brake either gradually or suddenly as desired. Another method of control is by means of an automatic switch which is placed in circuit in such a manner that the current strength from the motors is limited to that which will apply the maximum braking power, without making the car *skid* along the track.

The main advantages of an electromagnetic brake are the swiftness with which it can be applied and the fact that it does not depend upon the current taken from the trolley wire.

When the rails are slippery with mud or frost, the brake shoe sticks to the wheel and causes the wheel to skid or slip along the track. The result of this slipping is to wear the face of the wheel flat at one point of its periphery. Once a depression is formed there is considerable tendency to increase the amount of flattening, which makes the wheel very hard to brake and also produces a very disagreeable jolting motion. In order to prevent this

skidding as much as possible, sand is poured upon the track. This increases the adhesion between the wheels and track, to a greater extent than that between the brake shoe and wheel and thus prevents the brake shoe from sticking.

**Electrical Equipment.** The electrical equipment of the modern street car usually consists of the following:

| | |
|---|---|
| 2 motors. | 1 lightning arrester. |
| 2 gears. | 1 choke coil. |
| 2 pinions. | 2 canopy switches. |
| 2 controllers. | 1 fuse box. |
| 1 resistance box. | 1 trolley. |

Car wiring and cable details.
Lighting circuit details.
Heating circuit details.

These will be considered in the order named.

**Motors.** As direct current motors in general have been described in preceding instruction papers, only a short description will be given here. In designing and constructing street car motors, there are several important points which must receive proper consideration to produce an efficient, reliable, and economical machine.

*First.* Each individual part must be sufficiently strong, not only to resist the most severe strains that it will meet with in practice, but an extra margin of strength must be provided for safety.

*Second.* It must be designed with proper regard to accessibility of the various parts for inspection and repair. This is important on account of the naturally inconvenient position of the motor.

*Third.* All interior parts must be well protected from dirt and moisture.

*Fourth.* The perfect insulation of the field and armature windings is absolutely essential.

*Fifth.* It should be well ventilated, operate sparklessly and without heating up to extreme overloads, and have a high efficiency.

When the motor was first applied to railway work, it was simply an adaptation of the old bipolar machine to the new conditions. In these old machines, no protection to the armature and

field coils was provided. Even the gearing was uncovered, which exposure greatly increased the wear on the teeth. In the old types double reduction gears were necessary to reduce the speed of the motor to the proper speed for the car; but upon the advent of the low-speed, four-polar motor, a single reduction gear came into use, and is still employed. The modern motor is enclosed in a case, which forms the magnetic yoke between the pole pieces, and supports the shaft of the armature.

The G. E. — 800 railway motor built by the General Electric Company is shown closed in Fig. 7, and open in Fig. 8. The car axle runs in the bearings shown, its gear meshing with the pinion

Fig. 7.

on the right. The lower half of the case for enclosing the gears is shown in Fig. 8. The motor frame consists of two steel castings hinged on one side and bolted on the other. This provides a dust and water-proof casing for the armature, field and commutator. The frame is built in two forms, — in one the suspension is on the lower frame and the top frame is lifted for the purpose of removing the armature, in the other the suspension is on the upper frame, and is arranged for removing the armature from below. In the upper field casting a large opening is made in the commutator end which is covered by a hinged lid. This is provided with a felt gasket. The opening is made fo sufficient size to allow the

motor to be readily inspected and to permit easy access to the brushes.

The field consists of two salient and two consequent poles. The pole pieces are cast as part of the frame, and the field coils are secured in place around them by removable flanges. One of the pole faces is shown in the upper frame, Fig. 8. The field winding consists of asbestos covered wire wound on special formers without any spool or shell. After removal from the former, the coil is first

Fig. 8.

wrapped with canvas strips and then immersed successively in oil and japan and afterwards baked. This construction renders the coil impervious to moisture, protects it from mechanical injury and enables it to withstand such excessive temperatures as may result from overloading.

The armature is of the toothed type and provided with machine-formed coils. The commutator segments are cut from hard drawn

copper, and have a depth of $\frac{9}{10}''$, which gives a liberal allowance for wear.

The Westinghouse Electric & Manufacturing Company's 35 H. P. railway motor is illustrated in Fig. 9. A Westinghouse 25 H. P. motor with lower field and armature down is shown in Fig. 10. The field consists of four poles projecting radially inward from a cast steel yoke or frame which is divided horizontally. The pole pieces are composed of thin soft steel plates firmly secured together and cast into the yoke. This insures a strong magnetic field and eliminates losses due to eddy currents. The halves of the yoke are hinged together on the side opposite to the axle which gives easy access to the interior of the motor. The field coils,

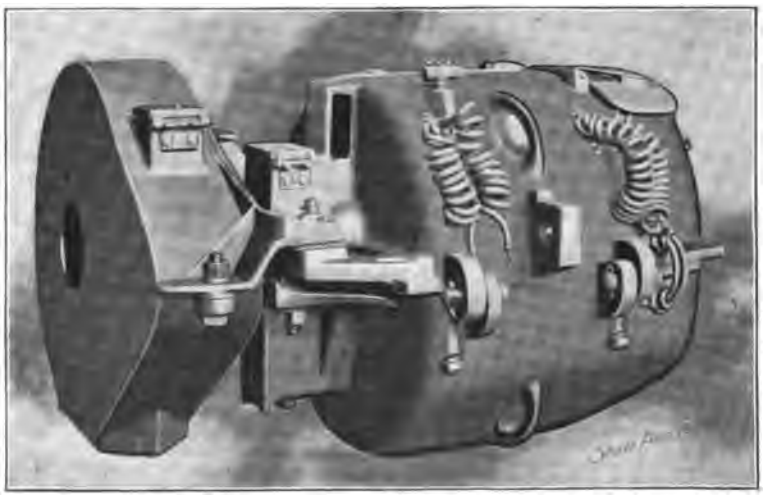


Fig. 9.

armature, commutator and brushes are completely enclosed by the upper and lower castings, which thereby protect them from dust and dampness. A large opening covered by a spring lid is provided in the upper casting directly over the commutator and brushes, and a hand hole protected by a water tight covering is located under the commutator in the lower casting.

The field coils are wound upon moulds in a winding lathe and thoroughly insulated with fullerboard and mica. One is then slipped on each pole and held in place by a cast brass plate bolted

to the yoke. The armature is of the drum type; the core is laminated and contains three air passages parallel to the shaft to provide ventilation. The coils are machine wound and placed in slots of the core; to increase the ventilation the coils are separated at the ends by air spaces. In order to make repairs, the car is run over a pit and the bottom field casting lowered, either with or without the armature.

The commutator is composed of hard drawn copper segments and insulating sheets of mica. A large number of segments are employed which reduces the sparking at the commutator and also

Fig. 10.

decreases the liability of flashing from any cause. The brush holders are secured to the upper field casting and provision is made for adjusting them radially to allow for wear of the commutator. Carbon brushes are used. The bearings and oil guards are outside the motor casing, which prevents oil from reaching the armature, field coils or commutator.

**Gears and Pinions.** The gearing usually employed in street railway work is effected by means of a steel pinion, ordinarily having 14 teeth, attached to the armature shaft and meshing with a gear wheel fixed upon the car axle. This wheel is

usually made of cast iron in two semi-circles, which are bolted together. The speed ratio is varied by changing this large gear.

Suppose the large gear has 67 teeth, then the speed reduction is $67 \div 14 = 4.786$. In other words the motor shaft runs 4.786 times faster than the car wheel axle. Now the circumference of a car wheel of 33 inches diameter, is 103.67 inches, or 8.639 feet. This shows the distance moved through by the car during one revolution of the car wheels. A speed of 88 feet per minute, and consequently a rotary speed of $88 \div 8.639 = 10.18$ turns per minute of the car wheels, corresponds to a speed of one mile per hour of the car. Speed of motor armature is therefore $4.786 \times 10.18 = 48.7$ turns per minute. Hence for every mile per hour that the car runs the motor armature will make 48.7 revolutions per minute. At 10 miles per hour it will make 487 revolutions per minute.

**Direct Connected** or gearless motors are not often used as they are expensive to construct, and require a complicated suspension. Owing to the armature being attached directly to the car axle, a flexible suspension is necessary to avoid hammering. This is accomplished by mounting the armature on a hollow shaft and attaching it by means of springs to the driven axle, which passes through it. A clearance of nearly an inch is allowed on all sides.

**Controllers.** The controlling apparatus for regulating the speed of the car, is second only in importance to the motors. One controller is mounted on each platform on the side opposite the brake handle. With single motors the rheostatic method of control is used. A variable resistance is then connected in series with the motor, and the speed varied by increasing or decreasing the amount of resistance inserted. Formerly this method was the only one used. The excessive loss of power due to heating of the resistance has proved a serious disadvantage. This wasted power often equals and sometimes exceeds that required to run the car itself.

In all modern equipments two motors are used, with what is known as the *series-parallel* method of control. The motors are started in series and afterward run in parallel through a number of intermediate changes.

Fig. 11 gives a diagram of the different connections made by

the "K" type series-parallel controller of the General Electric Company. A resistance *R* is shown at the left, then the armature and series field winding of motor No. 1 and No. 2 are represented. The following are the different combinations:

1. Motors in series and all the resistance in circuit.
2. Motors in series and half the resistance in circuit.
3. Motors in series and all the resistance cut out.
4. Motors in series and shunt around the fields.
5. Same as position 2.
6. One motor cut out, the other in series with half the resistance.
7. Same as position 6.
8. Motors in parallel with half the resistance in series.
9. Motors in parallel with no resistance in series.
10. Motors in parallel with shunt around the fields.

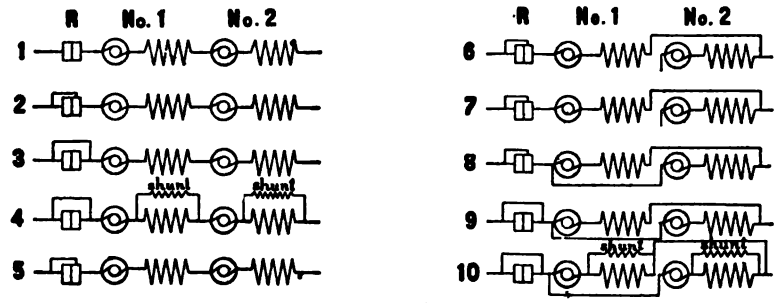



Fig. 11.

The points 5, 6 and 7 are to be rapidly passed over, being only transition points. The points 3, 4, 9 and 10 having all resistance cut out, are economical running points. The cutting out of resistance increases the E. M. F. applied at the motor brushes and consequently the speed. The changing of the motors from series to parallel increases the E. M. F. applied to each motor causing a further increase in speed. By shunting the fields the coils lose part of their current and the weakened fields also cause the speed to become greater.

The General Electric "K" type of series-parallel controller is illustrated in Fig. 12. The central cylinder, which is turned by the handle above, has insulated metallic contact strips mounted upon it. These are of varying lengths and arranged to make con-

tact with the fixed terminals at the left giving the series of connections shown in Fig. 11. A reversing switch is shown in the upper right hand corner. . An interlocking gear is provided which prevents the motors from being reversed until the current is turned

Fig. 12.

off. The terminals at the bottom of the controller are for the cables leading to the motors, resistance box, trolley and ground.

One of the greatest difficulties which had to be overcome in a controller was the rapid burning out of the contacts. As the

circuit has a potential of 500 volts and must be broken many times a day, some special provision for reducing the arcing is necessary. The General Electric Company overcomes this difficulty by means of the magnetic blow-out. This consists of an electromagnet connected in series with the main circuit. It is so arranged that the strong magnetic field it creates repels the arc formed and rapidly

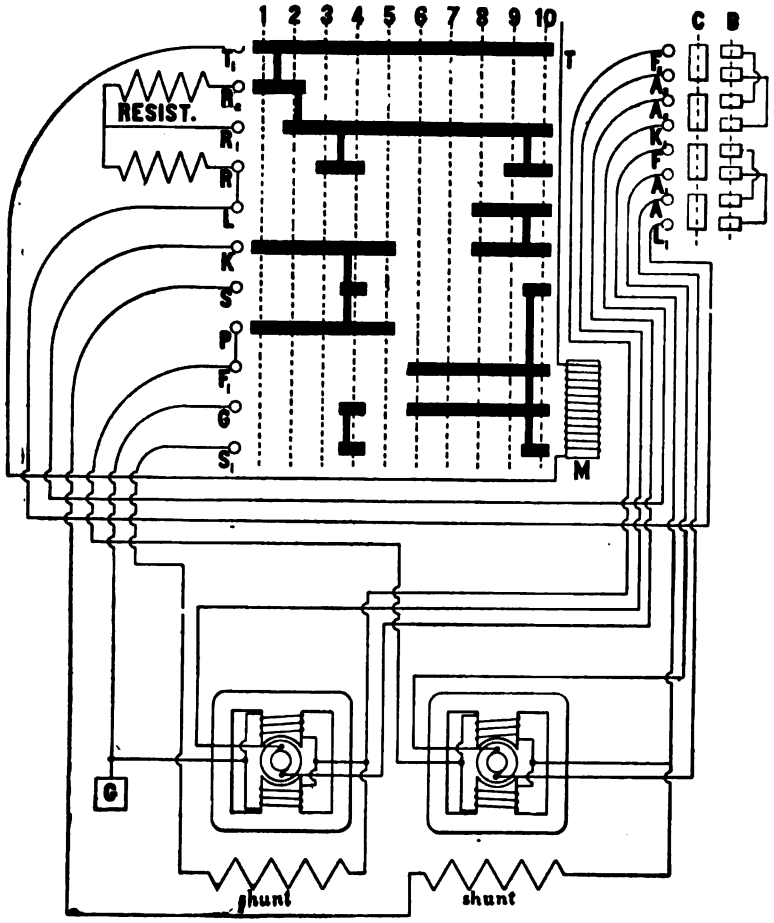
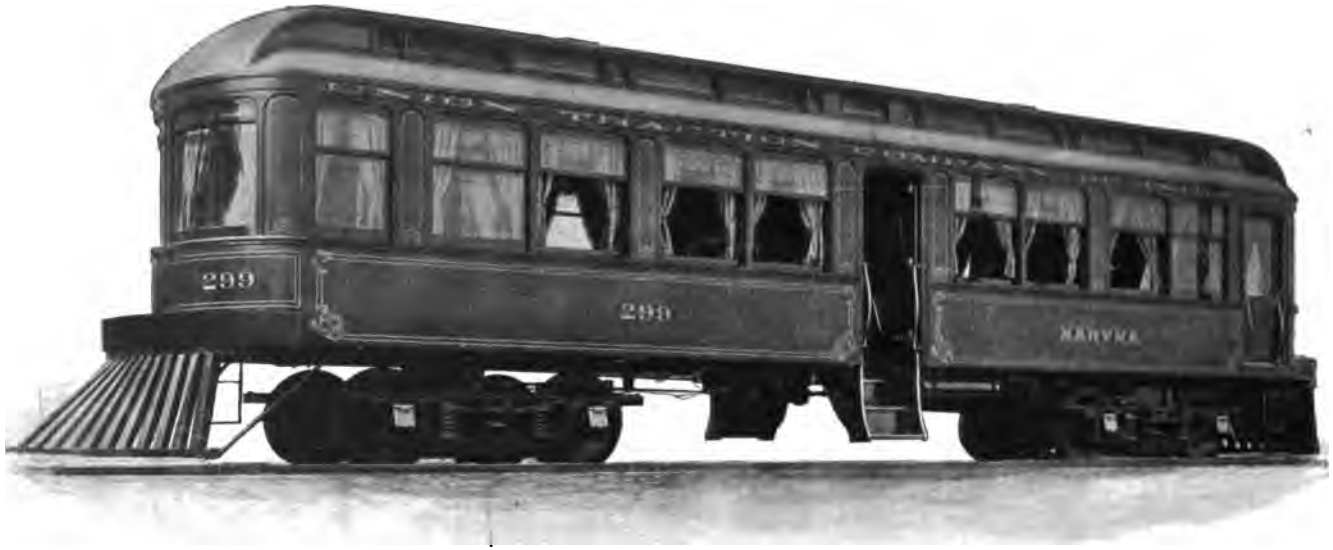



Fig. 18.

extinguishes or blows it out. The burning effect of the arc upon contacts protected by the magnetic blow-out is slight.

A development of the "K" type controller is shown in Fig. 18. The heavy lines represent the insulated conducting strips of




**High Speed American Electric Car built by St. Louis Car Co.**

the controller cylinder when unrolled on a flat surface. The terminals with which these strips make contact are represented at the left. The reversing switch is indicated in the upper right-hand corner. For forward running the contact points $F_2$, $A_3$, etc., are placed in contact with the conducting strips under $C$, thus connecting $F_2$ and $A_3$, $A_2$ and $K_1$, etc. For backward running these contact points are in connection with the strips under $B$ and $F_2$ is then connected with $A_2$, $A_3$ with $K_1$, etc., which reverses the direction of rotation of the motors.

The figures at the top of the diagram indicate the different positions of the controller cylinder. In position 3, for example, the terminals at the left are on the dotted line under the figure 3, and the connections are made as indicated for position 3 in Fig. 11. When the controller is in position 1, the connections for forward running are as follows: From the trolley $T$, around the magnetic blow-out $M$ to the terminal $T_1$ and upper conducting strip, down to second conducting strip to terminal $R_2$, through the full starting resistance to terminals $R$, $L$, $L_1$, $A$, through armature of right-hand motor to terminals $A_1$, $F$, through field coils of right-hand motor to terminals $F_1$, $P$, to conducting strip opposite $P$, up and out to terminals $K$, $K_1$, $A_2$, through armature of left-hand motor to terminals $A_3$, $F_2$, through field coils of left-hand motor to ground. For position 1, therefore, the motors are connected in series with all the resistance in circuit. For position 2 the connections are similar except that half the resistance is cut out or short circuited. The current then passes from the upper conducting strip to the second one below it, and out to terminals $R_1$, $R$, etc. Other connections may be followed out in a similar manner.

**The Resistance Box** usually consists of a cast iron frame containing coils of flat iron compactly wound between sheets of mica or asbestos. The principal function of this resistance is to reduce the current used when starting, so that the speed may be easily and gradually increased. It also allows great variation in speed and permits of slow running in crowded streets. The frame containing the coils is attached to the under part of the car body, and requires very little attention.

**Canopy Switch.** This is usually placed under the hood or

projecting roof of the car, in order to be within easy reach of the motor-man. One of these switches is placed at each end of the car. The current passes from the trolley through both of them in series, before reaching the fuse box. The current can therefore be cut off immediately by opening one of these switches.

The contact pieces in the switches are surrounded by some form of insulating material, usually slabs of slate. Destructive arcing is prevented by inserting another slab of the same material between the jaws of the switch. The whole is enclosed in an iron box lined with asbestos through which passes the handle used to throw the switch to the *off* or *on* position.

With some forms of controller a *cut-out box* is used, so that in case of accident, or damage to one motor, it can be cut out and the car operated with the other motor. It was formerly placed inside the car, under one of the seats, and consisted of two plugs, one being in the circuit of each motor. Of late years this cut-out has been included with the controller, the two plugs being placed in the lower part of the frame.

Fig. 14.

Fig. 15.

**A Fuse Box**, which is placed on a car wherever most convenient, but usually under the platform near the side, is used to protect the motors or other car apparatus from being burned out or damaged by dangerously large currents. The fuse is usually a piece of copper wire, of such a size that in case the current becomes too large for safety, the wire will melt and open the circuit.

There are a great many ways of mounting the fuse, but one of the best in use is an asbestos lined box, containing a block of wood, on which two thumb screw terminals are placed. The fuse is laid in a groove, running from one terminal to the other, and carries the total current supplied to the motors.

**Lightning Arresters.** These are used for protecting the motors and other apparatus from dangerous lightning discharges. Among the many forms of lightning arresters, the one shown in Figs. 14 and 15, invented by Mr. A. J. Wurts has proved very successful. It is designed to prevent dangerous arcing caused by the trolley current following in the path of the lightning.

This arrester consists of two metal electrodes one inch wide which are mounted upon a lignum vitæ block flush with its sur-

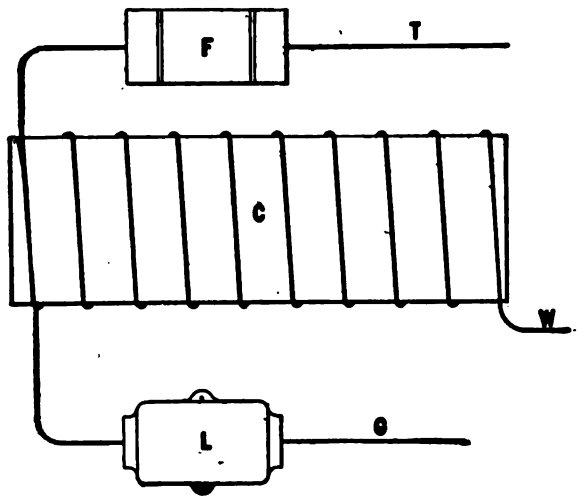



Fig. 16.

face. The block is provided with charred grooves, about $\frac{1}{16}$ inch wide, and $\frac{1}{32}$ inch deep. A solid lignum vitæ block is fastened over the other block, covering the grooves and the electrodes. The discharge passes between the electrodes over the charred grooves, which provide an easy path for currents of high potential such as lightning, but form an effective barrier for currents of 500 volts pressure. The resistance between electrodes is about 50,000 ohms. The arrester is non-arcing because the second block is screwed tightly over the other, allowing no space for any conducting vapors

to form. The whole is enclosed in an inverted cast-iron box with a lid on the bottom, and thus kept dry. A glass cup insulator, shown in Fig. 15, serves to separate the live parts of the arrester from the iron box and also provides a glass bushing for the centre lead which is connected to line. The ground connection is made to a lug-binding post on the iron box.

**The Choke Coil** is a coil of heavy wire, which is connected in series with the trolley wire, between the controller and the connection to the lightning arrester. The connections are shown in Fig. 16, where *T* represents the trolley leading in wire, *F* the fuse box, *C* the choke coil, *W* the wire to the controller cable, and *L* the lightning arrester, from which the wire *G* leads to ground.

The principle of the choke coil, lies in the fact that lightning, or currents of very high potential will pass through the small air gap of the arrester in preference to going through a coil of wire, on account of the high inductive effects therein produced. Lightning discharges will therefore pass through the arrester to ground and the motors and controllers are thus protected.

**Trolley Mechanism.** The trolley is the name given to the device for conducting the current from the overhead wire to the car. At the top of the trolley pole is the trolley wheel, which is maintained in rolling contact on the under side of the wire. One form of trolley wheel is shown in Fig. 17 and a trolley fork in Fig. 18. The wheel is made very light and usually of gun metal. It is supported in the fork by a spindle upon which it runs freely. A bushing of graphite is usually employed as a lubricator in preference to a metallic bushing using oil. The two springs shown in Fig. 18, bear against the hub of the trolley wheel, making a good electrical connection. These springs are connected with an insulated wire which passes down through the pole to the car.

Fig. 17.

The trolley pole is a tapering steel tube having its lower end mounted upon the trolley base. Springs are connected between

the base and pole in such a manner that a nearly uniform pressure, usually about 30 lbs., is exerted between the wheel and trolley wire.

A trolley base is illustrated in Fig. 19, the pole being fixed to the upper extremity. The two straps from the springs pass over

Fig. 18.

cams which maintain the line of action of the springs at a considerable distance from the axis. This insures an even pressure of the wheel against the trolley wire in the varying positions. The trolley may also be swung around when it is desired to run the car in the opposite direction.

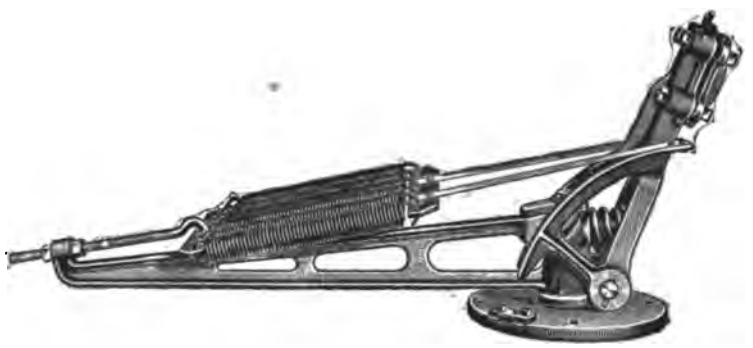


Fig. 19.

**Car Wiring.** Owing to the many styles of cars in use and the different types of apparatus, the methods of wiring are extremely varied.

Usually made up cables are used which have suitable taps for connecting controllers, resistances, and motors. Two cables are required for double motor cars, and also a separate ground wire. Each wire of the cable is cut off at the proper length, and is pro-

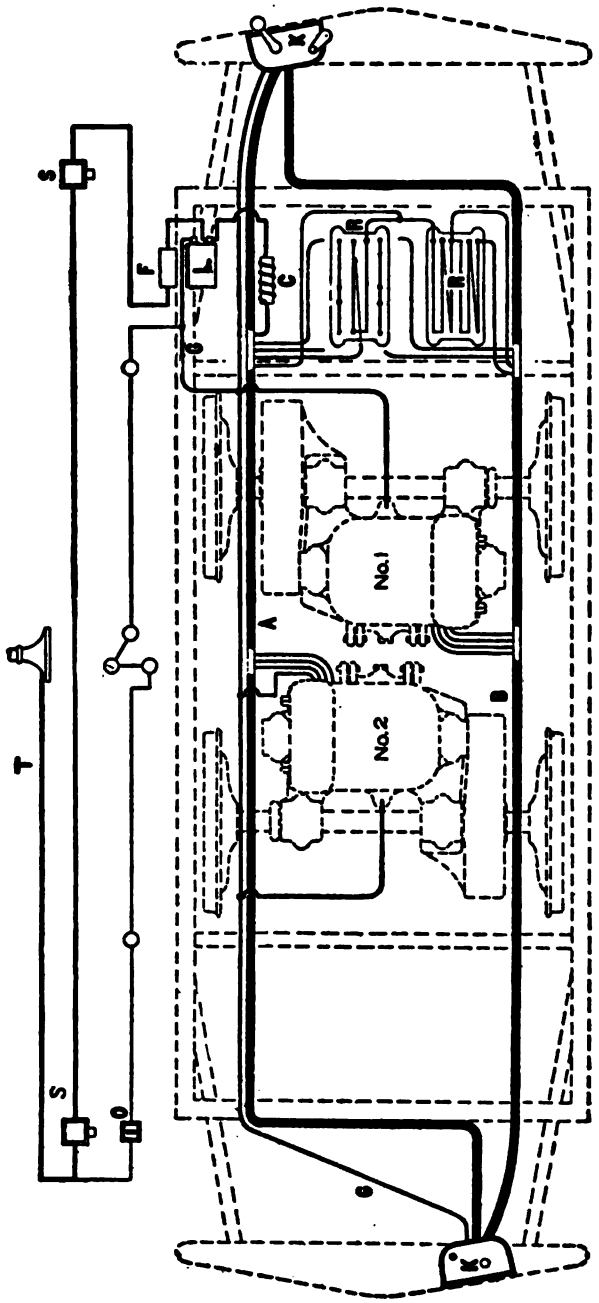



Fig. 20.

vided with a tag and number corresponding to numbers on the terminals of the motors and other apparatus. Mistakes in connecting up are thus avoided.

Fig. 20 gives a general idea of the wiring of a car. From the trolley *T* the main current leads through the two canopy switches *S S* to the fuse box *F* and lightning arrester *L*. From *L* leads a ground connection *G*. From the lightning arrester the current passes through the choke coil *C* to the cable *A*. This cable connects the controllers *K K*, and tap circuits lead to motor No. 2 and to resistances *R*. Cable *B* also connects the controllers, and tap circuits from it lead to motor No. 1 and to resistances *R*. A ground wire *G* extends between the controllers, the ground connections being made to the motor frames. The size of wire used for the main current is usually No. 6 B. & S. gauge.

**Lighting Circuits.** The advantages offered by the incandescent lamp for lighting trolley cars, are so evident that this method is almost invariably employed. A special lighting circuit as shown in Fig. 20, is taken from the trolley through a cut-out switch and fuse, shown at *O*, thence through the lamps in series to the ground wire. The type of lamp varies with the number to be used upon the car. Usually five 110 volt lamps are used, spaced at equal distances along the car ceiling. A cluster of three in the centre with one at either end is sometimes used. Other methods of wiring require nine or ten 55 or 50 volt lamps divided in groups, and with one lamp on the outside as a head light. Also, in some cases where ten lamps are used, two distinct circuits of five 110 volt lamps are run. The lamps most commonly used for street car work have an anchored or supported filament, to prevent damage from excessive vibration.

**Car Heating.** The electrical heater possesses such marked advantages over other forms of heaters for cars, that despite its greater cost, it has come into extensive use. When a current of electricity is passed through a wire, a certain quantity of heat is developed which varies directly as the resistance of the wire and as the square of the current passing. This is the principle of the electrical heater.

The heater made by the Consolidated Car-Heater Company consists of 392 feet of galvanized iron wire, No. 20 B. & S. gauge.

The wire is supported on porcelain tubes, which are in turn mounted on a square iron rod.

On the surface of the porcelain a groove is moulded, which runs spirally from one end of the heater to the other. In this groove the spirally wound resisting conductor is placed, after being drawn out sufficiently to prevent neighboring points of the spiral from touching each other. At the ends and centre of the heater are glazed porcelain discs on which the terminals of the iron wire are mounted, and which separate the heater into two parts for convenience of regulation. On account of the spiral form of the resisting conductor, the spiral binds closely to the insulator at all times whether hot or cold. It is not possible, therefore, for the wire to bunch and short circuit, when its length is increased by heat.

The heat is carried into the car by means of currents of air that enter at the bottom of the casing, which encloses the heating coil. The air becomes heated through contact with the heat radiating surface and then passes into the car through grated openings. The coils are placed under the car seats and opposite the grated openings in the seat riser.

Four heaters, and for long cars six, are placed in each car, two or three being located on each side. The heaters are so arranged as to distribute the heat within the car as uniformly as possible. This method of heating has the great advantage of delivering the heat near the car floor, where it is most needed for the comfort of the passengers.

When six heaters are used, a temperature regulating switch is employed to vary the amount of current supplied and consequently the amount of heat given off. The regulating switch has five different positions beside the *off* position, giving five different intensities or grades of heat. The switch consists of a cylinder of insulating material which carries in fixed position on its circumference pieces of conducting metal. Proper connections of the metal contacts are made through the substance of the insulating material itself.

The wiring of six heaters with regulating switch connections is shown in Fig. 21. The heaters are wired upon an independent circuit from the trolley $T$ to ground $G$. The six coils are represented at $R$, a development of the regulating switch at $S$, and a

cut-out at *C*. The wires leading from the heaters are connected to binding posts in the switch. These terminate in spring contacts which press against the surface of the switch cylinder. The cylinder may be placed so that any one set of the conducting strips *1*, *2*, *3*, *4*, and *5* may be placed in contact with the terminals *P*. In position *1*, the fourth and sixth terminals from the left will be connected, in position *2*, the second and sixth, etc. The different combinations of the resistance coils will be as follows: —

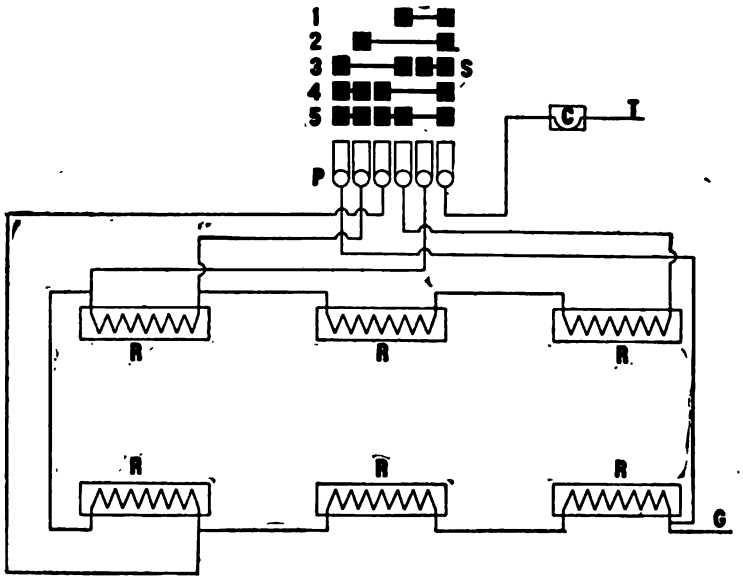



Fig. 21.

1. All coils in series, and the smallest amount of current is then taken from the trolley.

2. One-third of coils cut out, the remainder in series. By this connection the heat is increased about one-half.

3. Coils combined in multiple series of two, increasing the flow of current and consequently the intensity of heat.

4. One-third of coils cut out, the remainder in multiple series of two.

5. All coils combined in multiple series of three.

The amount of current used by these combinations varies from $2\frac{1}{4}$ to 12 amperes on a 500 volt circuit. With shorter cars using four heaters, the switch has three positions and the current varies from $2\frac{3}{4}$ to 8 amperes on a 500 volt circuit.

## TROLLEY LINE CONSTRUCTION.

The methods most frequently employed for supporting the trolley wire are the **span wire** system and **bracket** system.

Span wire construction requires poles in pairs, on opposite sides of the street. Fig. 22 shows this form of construction. The two iron poles *P P* are usually 27 to 30 feet long. They are made in three tapering pieces, each piece about an inch smaller in diameter than the one into which it is fitted. The poles extend into the ground a distance of 6 or 7 feet and are usually set in concrete. They are set slanting from the tracks, so that they can better bear the strain brought upon them by the weight of the

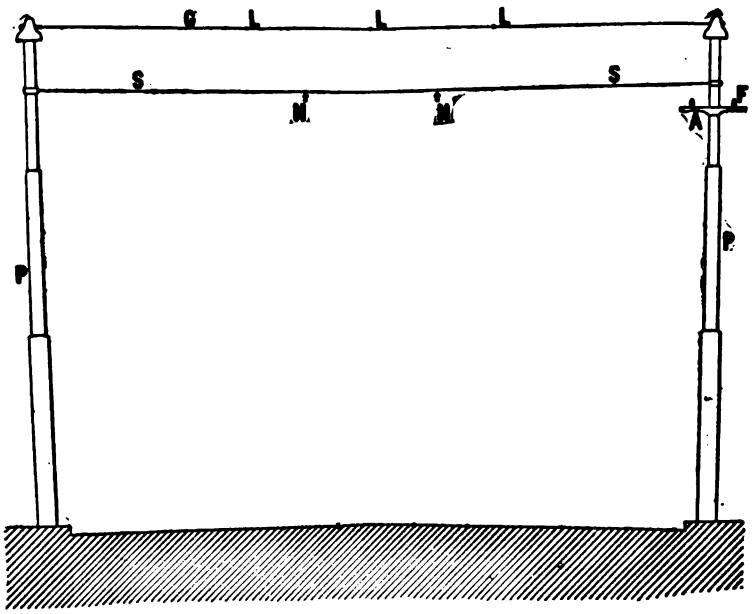



Fig. 22.

trolley wires. In cities the iron poles are used almost entirely, but wooden poles are commonly used outside city limits. The distance between poles along the road varies from 100 to 125 feet. The span wire represented by *S S*, is usually of No. 1 B. & S. iron wire and is attached to the pole by means of iron ring clamps. The span wires are stretched between the clamps under great tension. This depends upon the weight of the trolley wires, but is

usually about 500 pounds. Where only a single span wire crosses the street, it is often stretched between insulated tension bolts attached to the tops of the poles. Insulators *N N* are attached to the span wire, and support the two trolley wires running parallel to their respective tracks.

Since the trolley conductor is a bare wire, **guard wires** are sometimes used to prevent damage through contact with telephone and telegraph wires. These are of two kinds, the *span guard wires*, *G*, Fig. 22, which cross the street immediately above the span supports for the trolley wire, and serve as supports for the second kind, or *running guard wires*. These are attached by means of insulators at *L L L*, and run parallel with and above the trolley wire. They will then receive and intercept any wire falling from above. Feeders *F* are carried by the cross arm *A*, which is clamped to the pole.

The *bracket* suspension makes use of a single line of poles, even for double tracks. Poles used for double track work are placed vertically in the middle of the street between the tracks, and carry two brackets as shown in Fig. 23. This method is open to the objection of obstruction to traffic, except where special arrangements have been made on wide streets and boulevards to reserve the middle of the street for the traction company exclusively. With a single track the pole is placed at the side and carries a single bracket as shown in Fig. 24. The tops of the poles are sometimes used as supports for arc lamps. In the bracket system it is now the general practice to use a flexible form of support for the trolley wire hanger. This reduces the sparking and prevents

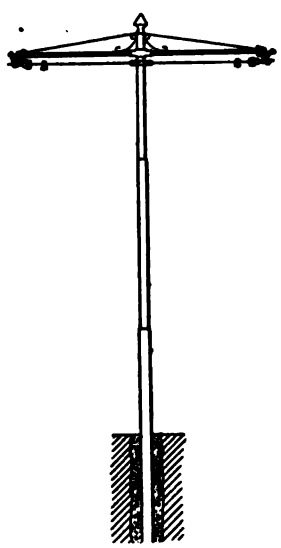


Fig. 23.

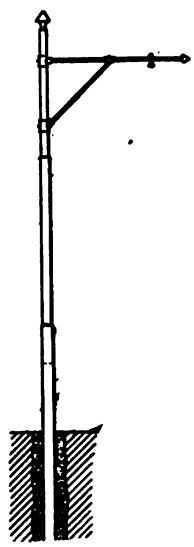


Fig. 24.

the destructive effects due to the hammer blow, when the trolley wheel passes.

The devices adopted for supporting the trolley wire from the suspension wire are of many different styles. It is necessary to support the wire firmly and at the same time to insulate it properly from the span wire. One of the common forms of straight line suspension, known as the *cap* and *cone* insulator, is shown in Fig. 25. The part *E*, a metal casting 15 inches long, is called the *ear*. This has a groove along its under side in which the trolley wire is placed. The trolley wire is held in position temporarily, until the wire receives its proper tension, by means of small tips shown at the ends. These tips are bent around the trolley wire,

Fig. 25.

and later soldered to it. Some forms have the tips extending the entire length of the ear. The body *B* of the suspension is made of iron and has two flanges at its extremities under which the span wire passes. The wire also bears against the head of the body on the opposite side, and the tighter the span wire is drawn the more rigidly the suspension is held in place. The cap *C* is of insulating material and has a bolt which screws into the ear. An insulating cone is between the body and the ear so that the span wire is well insulated from the trolley, and the latter is also firmly supported.

As the above form of suspension can sustain no lateral stress, a different form must necessarily be used upon curves. Fig. 26 shows a form of *double curve suspension*, so named on account of the two lugs of the body. In using this form it is necessary to cut the span wire and fasten the two ends to the ends of the lugs. The double curve suspension has the advantage, that the tension of the trolley wire exerts its force in the same plane as the tension of the suspension span.

Where the trolley wire is supported from one pole, on a curve,

a form of suspension known as the *single* curve suspension is used. This differs from the double suspension only in the number of lugs upon the body, having one instead of two. In the bracket suspension, the ear is sometimes supported rigidly by means of a cylindrical clamp fastened to the bracket arm, but more often by a form similar to the double curve suspension. The lugs of the latter are attached to a strong chain or wire, stretched taut, just below and parallel to the bracket arm, as shown in Fig. 23.

Fig. 26.

When it is necessary to connect two pieces of trolley wire, the joint is always made at an ear. Such an ear, called a splicing ear, is made in a great variety of forms. One type receives the trolley ends, under tips on the extremities of the ear, thence they are pushed through vertical openings in the ear and soldered in place. This ear is made in one piece of metal.

Fig. 27.

The practice of feeding current into the circuit at various distances from the power house, requires proper insulation of the various sections from one another. For this work a support known as a *section* insulator is used. One form is shown in Fig. 27. The trolley is connected to the ends of the insulator; and the wooden piece between the ends presents a straight runway for the trolley wheel. The upper bar, also of wood, is adapted to sustain the end strain as well as the weight of the trolley wire. The steel rod which is in tension is well insulated at the ends.

Although the trolley wire is insulated from the span wires, it is customary also to insulate the latter from the poles. The insulator for this purpose is combined with a turnbuckle for taking up slack in the span wire. Such a turnbuckle is illustrated in Fig. 28.

In order to keep the trolley line properly stretched and to

Fig. 28.

reduce the chance of accident, it is customary to introduce *anchor* or *guy* wires at about every 1,000 feet and at either end of every curve. These are represented by the inclined lines in Fig. 29, running from the poles to the trolley wires. The upper half of

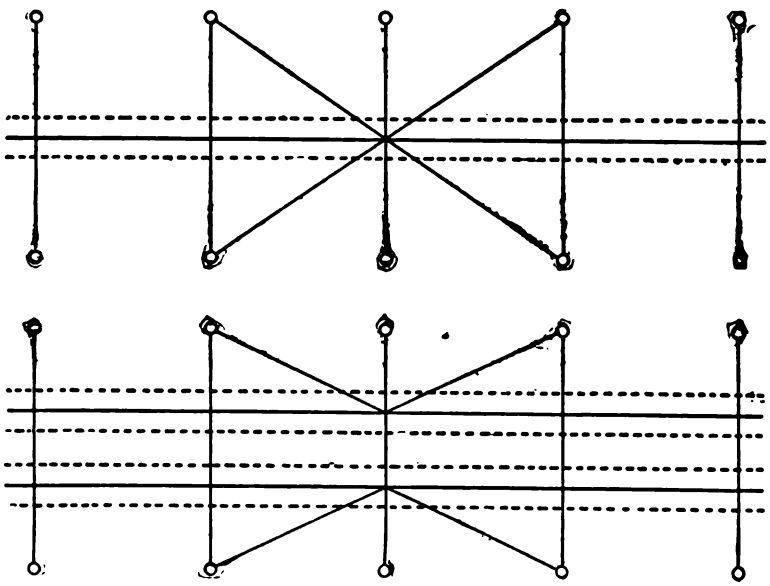


Fig. 29.

the figure shows single track anchoring and the lower half double track anchoring.

A special form of ear, shown in Fig. 30, is employed in this work. It has two lugs projecting from its upper surface, to which,

the anchor wires may be attached. A form of strain insulator much used for anchor wires consists of a spherical insulating mass about 2 or $2\frac{1}{2}$ inches in diameter, into which two iron eyes are cast. The connection is such that should the insulation break the iron parts will interlock and prevent the line from falling.

Fig. 30.

Fig. 31 shows various curve constructions, anchorages and position of poles.

When one trolley line branches from another, it is necessary to provide a guide for the trolley wheel. Such a device, known

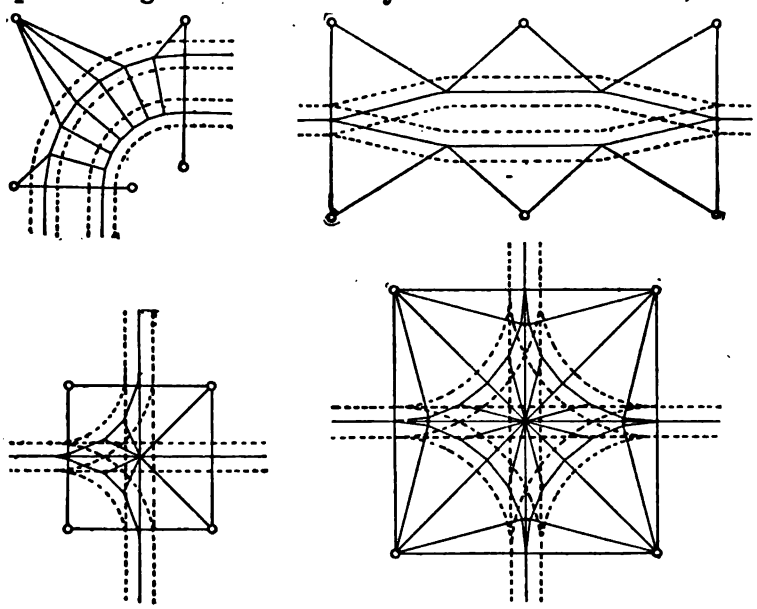


Fig. 31.

as a *trolley frog* or *switch*, is shown in Fig. 32. It is provided with projecting flanges on each side of a flat plate of metal, which serve to guide the wheel while passing. The electrical contact is made through the edges of the wheel instead of the grooved part. The ears to which the trolley wires are soldered, are so arranged with reference to the plate, that the wheel is neither raised nor

lowered when passing the frog. When a line branches into three parts, a switch known as a three-way frog is employed.

The position of the frog with reference to the track switches, varies according to the curve made by the branching line. Let *A A* in Fig. 33, represent the main line, *T* the main trolley wire, *B B* the branch line and *F* the branch trolley wire. Then forming a triangle with the points *C*, *D* and *E* as vertices and finding its centre *X*, gives the proper position for the frog.

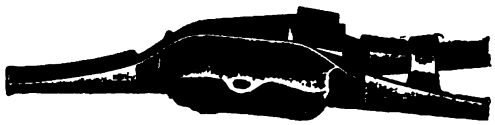


Fig. 32.

At the point of intersection of two trolley lines a trolley crossing, shown in Fig. 34, is used. Some crossings are made so that the angle is adjustable. When it is desirable to insulate one line from another, a form of crossing is used made up of a section insulator for one line and a metallic crossing for the other.

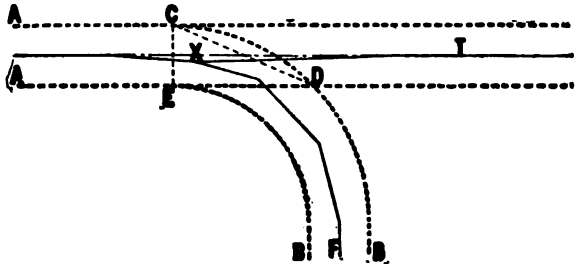



Fig. 33.

**Efficiency of Line.** As the load, that is the number of cars in operation at one time, increases, the efficiency of the line diminishes. If a current strength of 1 ampere is supplied to a circuit consisting of trolley conductor and track, having a combined resistance of 1 ohm, then the drop in the circuit will be, from Ohm's law ($E = IR$), 1 ampere $\times$ 1 ohm $=$ 1 volt. Hence if the pressure at the generator in the power station was 550 volts, the pressure at the motor would be only 549 volts. As the drop in a line is proportional to the amount of current flowing through it, if 3 amperes had flowed through the circuit the drop would have been 3 volts. The efficiency would therefore in each case

be the output divided by the input, or $\frac{548}{550}$ and $\frac{547}{550}$ respectively. To show the change more clearly let us increase the current strength to 100 amperes, then the drop would be 100 volts. In this case having 550 volts at the generator and 450 volts at the motor the line efficiency would be only $\frac{450}{550} = 0.818+ = 81.8+ \%$.

Fig. 34.

Now suppose we have a long line, say 16 miles, to deal with, using No. 0, B. & S. gauge wire, the resistance of which is approximately 8 ohms. A current strength of 50 amperes passing through the car motors at the extreme distance from the power house would produce a drop of 50 amperes $\times$ 8 ohms $=$ 400 volts, leaving only 150 volts pressure at the motors when the voltage at the generator terminals is 550, that is assuming no resistance in the ground return circuit. The input, or the energy delivered by the generator is 550 volts $\times$ 50 amperes $=$ 27.5 K.W. The energy available at the motor terminals is only 150 volts $\times$ 50 amperes $=$ 7.5 K.W. so that the line efficiency is only

$$\frac{7.5}{27.5} = 0.27+ = 27.+ \%.$$

The speed of the car is correspondingly reduced and it is evident that owing to the great length of conductor and the resistance of the circuit, much more energy would be expended in heating the wire than would be used to drive the car.

A similar condition of line efficiency would be produced by several cars on a short length of line. Consequently, when the distance over which cars are to run is great, or, when there are several cars to be supplied with a large amount of current, the amount of copper employed to supply the system must be increased so as to reduce the conductor resistance as much as possible. If for example we double the cross section of a trolley wire, we halve the resistance of the conductor, and therefore halve the potential drop which would occur at a given distance with a given load.

Example. — What would be the line efficiency of a simple trolley system, having a length of one mile and a resistance of .5 ohm, if 5 cars, each taking a current of 50 amperes, should start from the extreme end of the circuit? Assume the pressure at the generator as 550 volts.

Solution. — Total current supplied to cars $= 5 \times 50 = 250$ amperes.

$$\text{Drop in line} = IR = 125 \text{ volts.}$$

$$\text{Efficiency} = \frac{\textit{voltage at cars} \times \textit{current}}{\textit{voltage at generator} \times \textit{current}} = \frac{\textit{voltage at cars}}{\textit{voltage at generator}}$$

$$= \frac{550 - 125}{550} = \frac{425}{550} = .77 + \text{ or } 77 + \%.$$

Ans. $77 + \%$.

**Feeder System.** As it is practically impossible to increase the size of the trolley wire beyond certain limits, it is customary to use wire of a uniform size, say Nos. 0 or 00, B. & S. gauge, and prevent the great potential drop that would take place, by the use of feeders. A diagram of the feeder system is shown in Fig. 85.

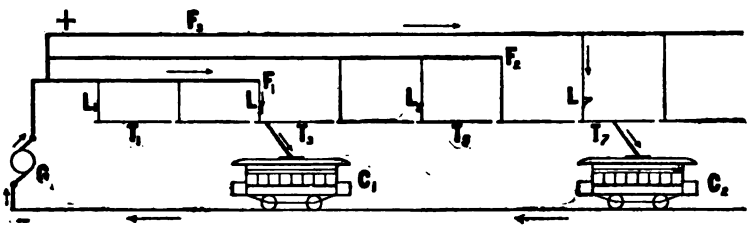



Fig. 85.

The feeding conductors $F_1$, $F_2$ and $F_3$ are separate from the trolley wires, and run along parallel to them either upon poles or in conduits, connecting with the sections $T_1$, $T_3$, etc., of the trolley wire at suitable distances along the track. These sections are insulated from each other, so that in case of accident or emergency, they can be immediately thrown out of circuit without interfering with the remainder of the system. This is accomplished by means of switches placed in the leading in span wires $L_1$, $L_3$, $L_5$, etc., from the feeder to the trolley.

It is evident from the diagram that the current used by car $C_2$ is supplied directly by the large feeder $F_3$, connecting with the positive bus bar at the station, so that the potential drop in

this case is much less than it would have been if the trolley wire were connected directly to the positive bus bar. The circuit is completed by the ground return to the generator *G*.

It is customary to arrange the feeders and distances between feeding points, so that when the total number of cars are being operated at average distances apart, the drop will nowhere be greater than 50 volts. That is, considering 550 volts as the pressure at the power station, the operating pressure at the motors should not fall below 500 volts.

## TRACK CONSTRUCTION.

The installation of an electric railway is almost invariably accompanied by reconstruction of the track previously used. This change is necessary on account of the greater relative weight of electric cars, and a strong firm track is needed to reduce hammering and jolting as far as possible. The greater speed of the electric car also requires a smooth roadbed to prevent excessive wear and tear on the rails and car, and the possibility of derailing.

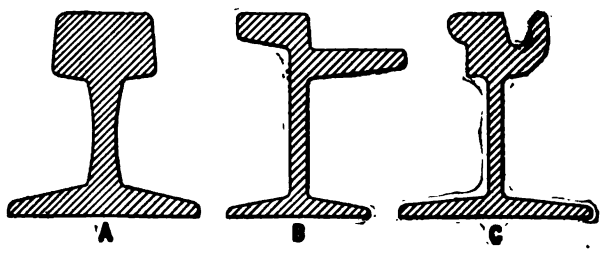



Fig. 36.

The most satisfactory rail for country roads and the smaller towns has proved to be the T rail (*A*, Fig. 36) as used on steam roads, and the tracks are usually constructed in a similar manner to those of the steam railway. In cities more care has to be taken with the track construction and it is customary to use either of the two forms of rail *B* or *C* in Fig. 36. These rails weigh from 60 to 90 pounds per yard, vary from 6 to 10 inches in height and are constructed so that the weight of the car wheel is applied directly over the web.

One of the best forms of construction for paved streets and for city work is shown in Fig. 37. The rails are laid directly on

wooden cross-ties *S*, to which the rails are spiked. The ties are placed about 3 feet apart. Iron tie rods *T*, measuring $1\frac{1}{2}$ inches by $\frac{3}{8}$ inch, are placed 6 feet apart. A foundation of gravel is sometimes required for the cross-ties. The paving blocks are set in a layer of sand about 2 inches deep.

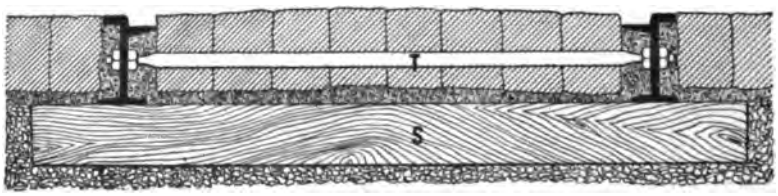



Fig. 37.

Fig. 38 shows two forms of joints which have given good results. Very heavy fish-plates are used for high rails, and from 8 to 12 one inch bolts in a double row are used to hold the rails together. The rails are usually placed with their ends close together.

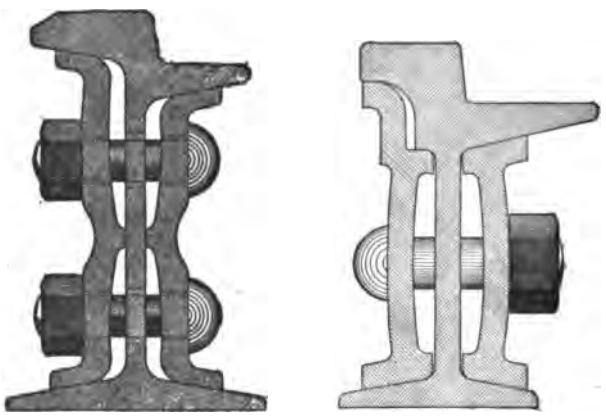


Fig. 38.

In order to ease the motion of a car on rounding a curve, the radius at the ends is made considerably greater than that of the main part of the curve. A curve of 40 feet radius may have an initial radius of 100 feet, then 75 feet and finally 40 feet, giving a gradual approach. Such curves are called *transition* curves.

**Bonding.** When the ground return is used it is necessary to secure as nearly a continuous path for the current as is possible.

Mere contact between the ends of the rails and fish-plates is not sufficient as the formation of rust introduces a very high resistance into the circuit. In order to secure a more perfect metallic circuit various methods of bonding the rails are in use. The Chicago *rail bond*, which is the one most generally used, is shown in Fig. 39. When this form of bond is used, the rail is drilled a short distance from the fish-plates, and the ends of a copper rod are pressed into the holes, one end in each rail as shown. A plug is then driven into the opening of the rod ends, wedging it tightly into the rail.

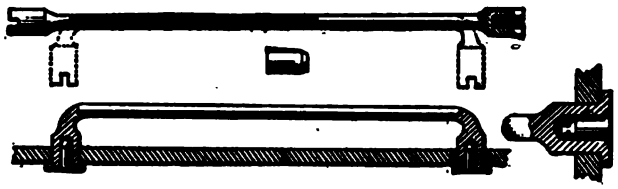


Fig. 39.

From a purely electrical point of view, the electrically welded joint or rail bond is the most efficient, although considerable trouble has been experienced in some cases due to the expansion and contraction of the rails, causing buckling and distortion. Melted cast iron poured into a mould surrounding the joint of the rails, has been used to answer the purpose of a bond and to form a solid joint.

Fig. 40.

A rail bond which has come into use recently is the protected rail bond, shown in Fig. 40. Holes are drilled through the web of the rail about two inches from the ends, and the lugs shown at the ends of the bond are expanded into these holes under great pressure. The bond is made of copper, is about four inches between centres and is entirely protected by being placed under the fish-plate.

## ELECTROLYTIC EFFECTS.

When an electric current is passed through water, there takes place a decomposition of the water into its constituents, oxygen and hydrogen. These gases are liberated only at the points of entrance and exit of the current. If the electrodes are made of oxidizable material, such as iron, copper, lead, zinc etc., the electrode through which the current passes into the water becomes corroded or oxidized, while the other is not deteriorated. The second electrode is in reality increased in weight at the expense of the first.

It is only by virtue of the moisture present in the ground that we are able to use the earth as part of an electrical circuit. If two plates are buried in the earth and a current of electricity passed from one to the other, the chemical actions are similar to those which take place when a current is passed between two electrodes in water. It is evident therefore, that wherever the ground is used as a return circuit, the metallic surfaces by means of which the current enters or leaves the ground are subject to electrolytic action. The corrosion of gas and water pipes along the lines of electric railways using the ground return has proved to be very serious.

When the rails serve as the return circuit, they conduct only a part of the total current back to the dynamo. The remainder leaves the rails mostly in the neighborhood of the cars, but partly between the cars and station, and returns to the dynamo through the ground. This division of current depends upon the efficiency of the bonding and the amount of moisture in the earth. At points where the current leaves the rails corrosion will take place, its extent depending upon the amount of moisture present and amount of electricity passing into the ground.

If it were possible in large cities to limit the corrosive action to the rails alone, the consequences would not be so serious. Here the network of metallic piping forms excellent conductors, and where parallel to the track such conductors convey a considerable portion of the current to the power house. Under favorable conditions about one-half of the total current returns to the power house through the rails, about one-eighth is diffused through the ground, and the remainder is conducted by water mains, etc. As the cars are distributed over a considerable area,

and likewise the points where the current leaves the rails, the deterioration of the latter is comparatively slight. The current flowing through the pipes is conveyed by them to the vicinity of the power house, and there *leaves* the pipes over a relatively small area. On account of this restricted space the electrolytic action at this point will be comparatively great and the pipe quickly destroyed. In order to prevent this, and reduce the action to a minimum the negative terminal of the generator is placed in metallic connection with the pipes in the vicinity of the power house. At points remote from the station since the current there passes *to* the pipes, the latter are actually built up at the expense of the track.

If the negative pole of the generator is connected to the trolley and the positive to the track, the corrosive effect will take place where the current leaves the pipes at a distance from the station, and where the current leaves the track near the power house. As the area of the pipes over which the corrosion will then take place is very extended, the amount of corrosion on any one length of pipe in the district will be correspondingly diminished; continued action, however, would gradually destroy the whole piping system.

## THE POWER STATION.

The essential features of a power house on the mechanical side are: The machines for generating the current, the engines to drive the generators, and the boilers to supply the power to run the engines. On the electrical side are: The switchboards, leads, connections, feeders, measuring appliances, and regulating and safety devices.

**Location.** The location of the station will depend mainly upon the system it is to supply. It should be placed so that the districts carrying the heavier loads are relatively nearer to the station, thus avoiding the loss due to the transmission of a heavy current through a long system of feeders. Among other factors to be considered is the cost of land, as the best power houses are now built covering an immense area and only one story in height. The cost of coal transportation and the water supply should next be considered. It is very desirable to build on a water front, as then the coal can be brought directly to the station in barges.

A station centrally located may supply a system of about ten miles radius. During the past few years, in many instances, railways in small towns have been supplied with power from a plant situated several miles away from the town where water power is available. Even small streams having sufficient head of water, are used to drive the turbines which in turn run the generators.

**General Plan.** The station is divided into two main rooms separated by a substantial fire-proof wall. In one are located the boilers, and in the other the engines and dynamos. For convenience in erecting auxiliary apparatus, running pipes, mains, etc., the engine room usually is provided with a basement.

The general arrangement of apparatus must be such, that there is little chance of a complete shut down. All parts must be able to stand sudden stresses, due to sudden changes of load, and be easily accessible.

**Boilers.** The boilers are usually of the water tube or return tubular type. The former type is usually preferred on account of its quickness in getting up steam and greater safety. Where space is limited vertical boilers are used.

Labor is an important item in the power house and every means should be taken to reduce this as much as possible. The boiler room should be designed with a special view to handling the coal and ashes conveniently and expeditiously. If possible the arrangement should be such as to allow the coal to be directly discharged from the hold of a ship into the bunkers, or similarly from a railroad car on a raised track. The bunkers should be directly opposite the fire doors. Usually small cars are run into the boiler room on a track and the ashes shoveled into them and thus easily removed. Very large plants are sometimes equipped with special conveyors and elevators for handling the coal and ashes.

**Engines.** On account of the great and rapid fluctuations in load arising in electric railway work, it is essential that all component parts of the engine should be of extra strength. The regulation is also of great importance and from no load to full load the speed should not vary more than two per cent. The fly wheel should have sufficient weight not only to reduce the fluctuations in speed but to assist in carrying momentary overloads. In the case of small roads the best regulation would be obtained by means of

high speed engines connected by belts to the dynamos. For roads of large capacity where the percentage fluctuation is less, the best results are obtained by slow speed direct connected units.

**Generators** for electric railways are compound wound to give as nearly as possible a constant potential, of from 500 to 550 volts. They are usually over-compounded to give a rise in voltage of 10%, from no load to full load. The generator should be able to stand a considerable change of load, with but little sparking at the brushes. The heating effects should be low, and all parts should be readily accessible.

**Size of Units.** The capacity of the plant is dependent upon many factors such as number of cars, grades, nature of service, etc. The method of determining the power required per car is given on a following page. From an average of a large number of electric railways it has been found that the approximate indicated horse-power required at the power house for various sized car equipments is as follows:

| Number of Cars. | Indicated H. P. per Car. |
|---|---|
| 1 to 5 | 35 |
| 5 to 10 | 30 |
| 10 to 15 | 25 |
| 15 to 25 | 20 |
| 25 to 50 | 15 |

The size of units to give the best results is rather difficult of determination. Large machines are the most economical, but should of course be run at or near their full capacity to give a high efficiency. The following table taken from a report made at the twelfth annual meeting of the American Street Railway Association, shows the capacity and number of engines recommended for different stations.

| Maximum I. H. P. Required. | No. of Engines Recommended. | I. H. P. of Each Engine. |
|---|---|---|
| 200 | 2 | 200 |
| 400 | 3 | 200 |
| 600 | 3 | 300 |
| 1,000 | 3 | 500 |
| 1,500 | 4 | 500 |
| 2,000 | 4 | 750 |
| 5,000 | 6 | 1,000 |
| 10,000 | 8 | 2,000 |

It is evident from the table that besides the number of engines for furnishing the power required, there is an additional engine in reserve to be used when one of the others is being repaired.

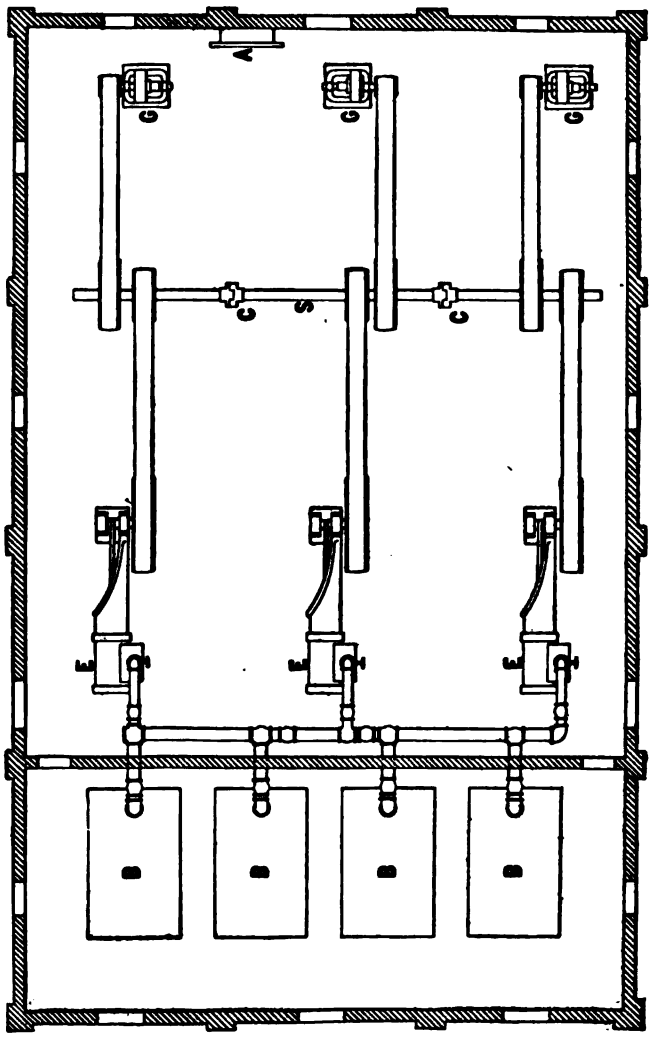



Fig. 41.

**Steam Piping.** The demands upon a railway power plant vary greatly from hour to hour during the day, and in order to run the plant economically, some method of piping must be devised, so that the proper amount of power can be produced with

the minimum consumption of coal. The simplest way would be to connect each engine to a separate boiler, and cut out the whole unit when not required. The most serviceable system, however, is that where each boiler in a battery is connected to a large main running the entire length of the boiler room. This is provided with a series of valves so that any boiler, or any section of the main can be cut out when not needed, or in case of an accident. This main is run just below the ceiling of the boiler or engine room, and is connected at proper intervals with the supply pipes to the engines.

**Belting.** Fig. 41 gives a general idea of the ground plan of a small station using belted generators. Three high speed, short stroke engines *E*, have their fly-wheels belted to a common shaft *S*, running across the engine room. This shaft is divided into three parts by means of clutches *C*, and each part may be run independently, or connected with the other two. The shaft is belted directly to the generators *G*, as shown. By means of a system of friction pulleys it is possible to drive any generator by any of the three engines, thus allowing any combination of engines and generators in case of accident. The switchboard *A*, should be placed in such a position that any accident to the belting would not be likely to injure the delicate instruments upon it. On the other side of the fire wall the boilers *B*, are placed in such a position relative to the engines, that the loss by condensation in the steam pipes is reduced to minimum.

**Direct Connection.** It has now become the universal practice, except in small stations, to directly connect the generators and their engines. The losses due to belting often run from ten per cent at full load to forty per cent at one-third load. The decreased floor space required for direct connection gives this method a further great advantage where the cost of real estate is high. The elimination of danger, wear and tear of belting, reduction in noise, and better appearance, are other points in favor of direct connection.

## SWITCHBOARDS.

The electric railway switchboard has now assumed a form especially adapted for the work required of it, is simple in construction and operation, and ornamental in appearance. A modern

switchboard installed by the General Electric Company is illustrated in Fig. 42. The switchboard is divided into separate units called panels. Each panel consists of a slab of marble or polished slate supporting all the appliances needed to measure, regulate

Fig. 42.

and distribute the current from a single generator, or that supplied to a single feeder system. The panels are made of a standard size uniform in height so that the general appearance of any number of panels is regular and symmetrical.

The panels are divided into two classes, — the *generator panel* and the *feeder panel.*

**Generator Panel.** At the top of this panel is the **circuit breaker.** This is a main switch capable of adjustment to automatically open the circuit when the current exceeds a certain value. Its function is to protect the generator and other apparatus from damage due to overloads by limiting the current to a predetermined value.

Fig. 43

The General Electric circuit breaker, illustrated in Fig. 43, is very generally used. This is provided with a magnetic blow-out and circuits of high amperage may be safely opened. The current in passing through the circuit breaker is carried normally by heavy copper contact brushes, which set upon large square studs shown in the centre of the figure. The brushes are held in place by a

latch which is tripped by the armature of an electromagnet, through the coils of which the total current passes. This coil is shown in the lower left-hand corner. The strength of current which will cause the tripping and thereby the breaking of the circuit is regulated by an adjustable spring above the magnet.

The breaking of a five hundred or six hundred volt circuit is likely to cause considerable arcing unless some means is taken to prevent it. Damage is avoided in this type of circuit breaker by the use of supplementary contacts arranged so as to break the circuit an instant after the main contacts, and placed in a strong magnetic field. This causes the arc to be blown out before burning can occur, even with the highest currents and voltages used in railway work. These supplementary contacts are placed inside the hood-shaped piece at the top of the circuit breaker. This transfer of the arcing points, and the use of the magnetic blow-out has enabled efficient circuit breakers up to 8,000 amperes capacity to be constructed.

The *measuring instruments* most generally used on generator panels are of the illuminated dial pattern. The **voltmeter** which serves for a whole range of panels, is usually placed on a swinging arm or bracket, so as to be set at any desired angle to the face of the switchboard. Voltmeter mains are carried along the back of the series of panels and the proper connections are made by the insertion of a voltmeter plug at the panel where the potential is to be taken.

The **switches** used on railway panels are quick-break, having the blades in two parts connected by a stiff spring. When the handle is moved to open the circuit one section of the blade does not leave the contacts until the spring is under considerable tension; the break is then made very quickly and arcing is largely avoided. These switches are not, however, ordinarily used to open the live circuits; the automatic circuit breaker, which has also a hand tripping device, being commonly used for this purpose. The switches are single-pole, as it has been found that the starting and shutting down of generators running in multiple is more conveniently and safely accomplished by making the positive and negative switch blades entirely independent.

The **equalizer switch**, which is used when generators are

thrown in or out of circuit, according to the demands of the system, sometimes appears as a third blade upon the generator panel, but is more often located on a pedestal near the generator. This gives better regulation and saves length in conductors.

The **field rheostat** is usually attached to the back of the panel, only the hand wheel and index appearing on the front. The type and capacity of a rheostat varies with the field winding of the generator for which the panel is employed.

**Feeder Panel.** The use of this panel is the most convenient method of distributing current to one or more sets of feeders of a system. The current from any number of generators is transferred at the generator panels to the main bus bars. These are large heavy copper bars, which extend on the back of the switchboard through the whole range of panels. The separate feeders for street distribution are attached through the switches and cut-outs of the feeder panels and each feeder can be controlled independent of any other. In large power stations fifty to seventy-five panels are sometimes combined into one board.

The apparatus belonging to a feeder panel includes either a circuit breaker or a fuse. Some panels of small capacity are fitted with copper fuses which serve as a protection, and although not so effective nor so convenient as circuit breakers, occupy less space when several feeders are served from one panel. The feeder switches are quick-break and similar to those used on the generator panels. Small round pattern ammeters are used to indicate the current in the feeders.

Panels equipped with lightning arresters are provided with a spiral of heavy copper on the back of the panel. This spiral serves to choke back a lightning discharge from the board and force it through the easier path of the lightning arrester to the ground. Generator panels do not have these coils as a portion of the generator cable is wound into a flat coil and serves the same purpose.

In addition to the above panels there is in the large power houses a panel called the **total output panel.** This carries *total current* ammeters, and wattmeters for measuring the total current and kilowatt output of the station. The use of a wattmeter enables a close check to be kept upon the work done by the

apparatus, and has been found of great value both in large and small stations. The Thomson recording wattmeter is most extensively used for this work.

The position of the switchboard depends upon the requirements of each case. It should be easily accessible and located so that a good view of it may be obtained from every part of the engine room. The distance to the generators should be as short as possible and to the different machines about equal. The direction in which the feeders must leave the station should also be considered.

## ACCUMULATORS IN POWER PLANTS.

On account of the great fluctuation in the load in electric railway work, the accumulator may in some cases be used with excellent results. These fluctuations are especially noticeable in small plants, where the demand may vary from zero to a maximum in a few seconds. By being charged at low loads and discharged at heavy loads, the accumulator serves to regulate the pressure, reduces the strains on the engines and generators, and allows the use of a considerably smaller generating plant.

Accumulators are sometimes placed at suitable points along the line, allowing much of the feed wire to be done away with and improving the equality of pressure. Such an auxiliary plant requires but little attention, and in case of a temporary stoppage of generators or of a break in the supply circuits, such a source of supply would be very valuable. An installation of this kind may be arranged to carry the whole load when only a few cars are running.

The storage battery plant of the Union Traction Company of Philadelphia is an example of an auxiliary plant. It acts as a sub-station in operating a division of the system eleven miles from the power house, and permits the number of cars on this section to be doubled without increasing the amount of feeder copper. The battery consists of 248 cells in lead lined tanks, capable of discharging at 500 amperes in regulating the excessive fluctuations of load. The feeder to the battery carries a steady current of the average amount required for the work. Thus, with a varying demand upon the section of from 100 to 800 amperes, the feeder

**A NEW YORK CITY CHARGING STATION FOR CHLORIDE AND EXIDE AUTOMOBILE BATTERIES.**
(Equipped by the Electric Storage Battery Company.)

carries a constant load of about 400 amperes. The voltage is maintained practically constant upon the line irrespective of the changes in load.

## POWER DETERMINATIONS.

The following formula has been used to deduce the power required for propelling a car of known weight, over a level track under normal conditions.

$$P = 30\ t$$

where $P$ = required force in pounds,

and $t$ = given weight of car in tons.

For example, suppose a car weighing 15 tons is taken. Required the force in pounds which will keep the car in motion. In the above formula, $t = 15$,

then, $P = 30 \times 15 = 450$ pounds.

Ans. 450 pounds.

When grade of track and speed of car are considered a very different problem is presented. The number of foot-pounds per minute required under given conditions of speed and grade, is determined by adding the product of the weight of the car by the perpendicular distance in feet through which it is raised, and the product of the horizontal distance in feet, traveled in one minute, by the force in pounds necessary to move the car on a level track. This sum divided by 33,000 will give the total horse-power that is to be applied to the car. Owing to a power loss in the transmitting mechanism, it is necessary to supply greater power to the motors. This increase of power depends almost wholly upon the efficiency of the motors.

**Power Diagrams.** Instead of using formulas, the diagrams, shown in Figs. 44 and 45 may be used to determine very quickly the horse-power required to propel a car of known weight under known conditions of speed and grade. In Fig. 44 the abscissas represent the number of miles per hour that the car is traveling, and the ordinates represent the number of horse-power required for each ton weight of the car. The inclined lines represent a certain per cent rise, that is, a grade of 5% represents a rise of five feet, while the car is travelling 100 feet. In Fig. 45 the ordinates are the same as those of Fig. 44, but the abscissas repre-

sent the total horse-power required for the car. The inclined lines represent cars of different weight.

Suppose for example, it is required to find the horse-power

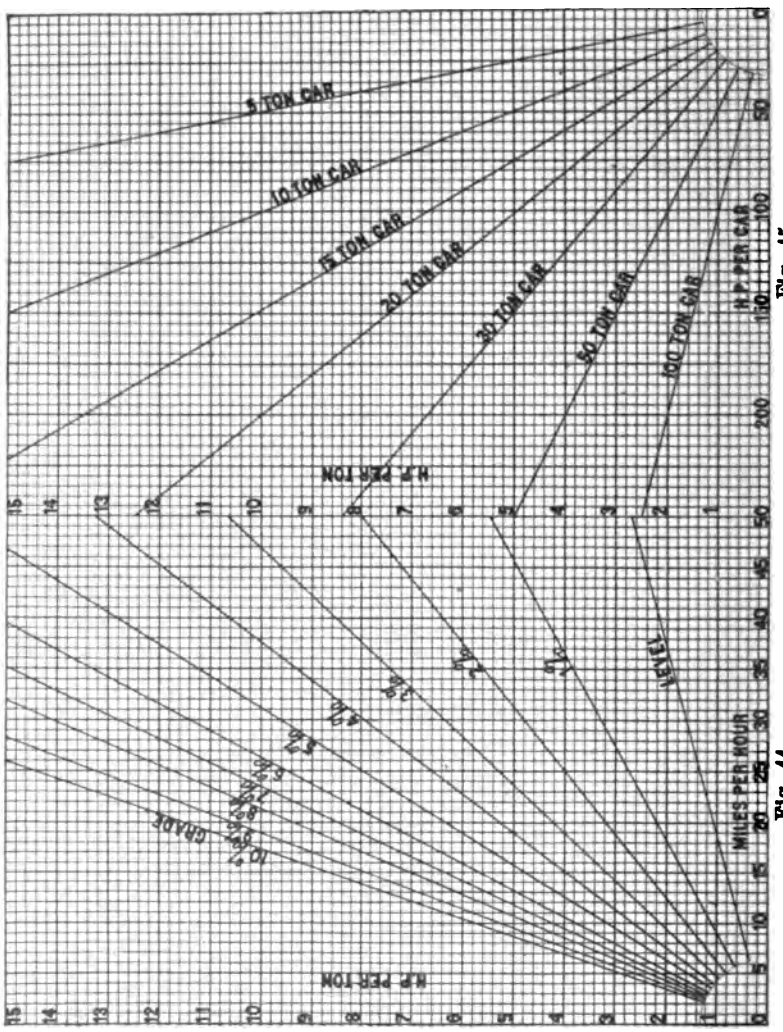



Fig. 45.

Fig. 44.

needed to operate a 20 ton car at 10 miles per hour on a 5% grade. Referring to the abscissas of Fig. 44 we find the point which represents a speed of 10 miles per hour; following the ordinate from this point until it intersects the oblique line repre-

senting 5% grade, and then following the horizontal line through this point of intersection, we find 3.1 as the value of the ordinate. This shows that 3.1 horse-power per ton is required to propel a car at 10 miles per hour on a 5% grade. Multiplying this by the weight of the car in tons, we have $3.1 \times 20 = 62$ H. P., as the power required to operate the car. The same result might be obtained directly from Fig. 45 by using the same ordinate (3.1) and projecting horizontally to the line representing a 20 ton car, and from this point of intersection, dropping a perpendicular, and determining the value of the abscissa of this point. The result (62) is the total horse-power required, therefore if the car is to be equipped according to the usual custom, with two motors, the capacity of each should be one-half the total horse-power. In the case mentioned two 30 horse-power motors would fill the requirements. The capacity of the motors required for other conditions may be found in a similar manner.

The power required when a car is rounding a curve, depends upon the radius of the curve, and upon the style of truck used. When starting a car much more power is required than is expended in keeping the car in motion.

The great number of factors which tend to vary the adhesion of the car wheel to the rail make it almost impossible to determine the maximum tractive force that could be applied to the wheel, without causing slipping. There is a sort of welding action between the car wheel and the track, varying with the amount of current passing through the point or line of contact, so that the maximum tractive force of cars running upon rails which form part of the return circuit, is much greater than that of any self-contained locomotive of the same weight.

Example. — Suppose a two motor car weighing 20 tons, is going up a hill at a speed of 15 miles per hour, the hill rising 3 feet in every 100. (*a*) Find approximately the power required to be delivered by each motor. (*b*) If the efficiency of the motors is 75%, find the power which should be supplied to each motor.

Solution. — Following the vertical line at 15 in Fig. 44, to the 3% line, gives the value of the ordinate as 3.2 H. P. per ton. Following across to the 20 ton car line and dropping to the base

line, we find the H. P. required to be approximately 65, and the H. P. required to be delivered by each motor is $\frac{1}{2} \times 65 = 32+$.

If the efficiency of the motors is 75%, then the output is equal to 75% of the input, and the input being 100%, the output or $32 = 75\%$. Hence $1\% = .43$ approximately, and $100\% = 43$ H. P. approximately.

Ans. { (*a*) 32 H. P. (approx.)
(*b*) 43 H. P. (approx.)

Example.— How many men would be required to pull a car along a level track if the car weighed 30 tons, and each man pulled with a force of 150 pounds?

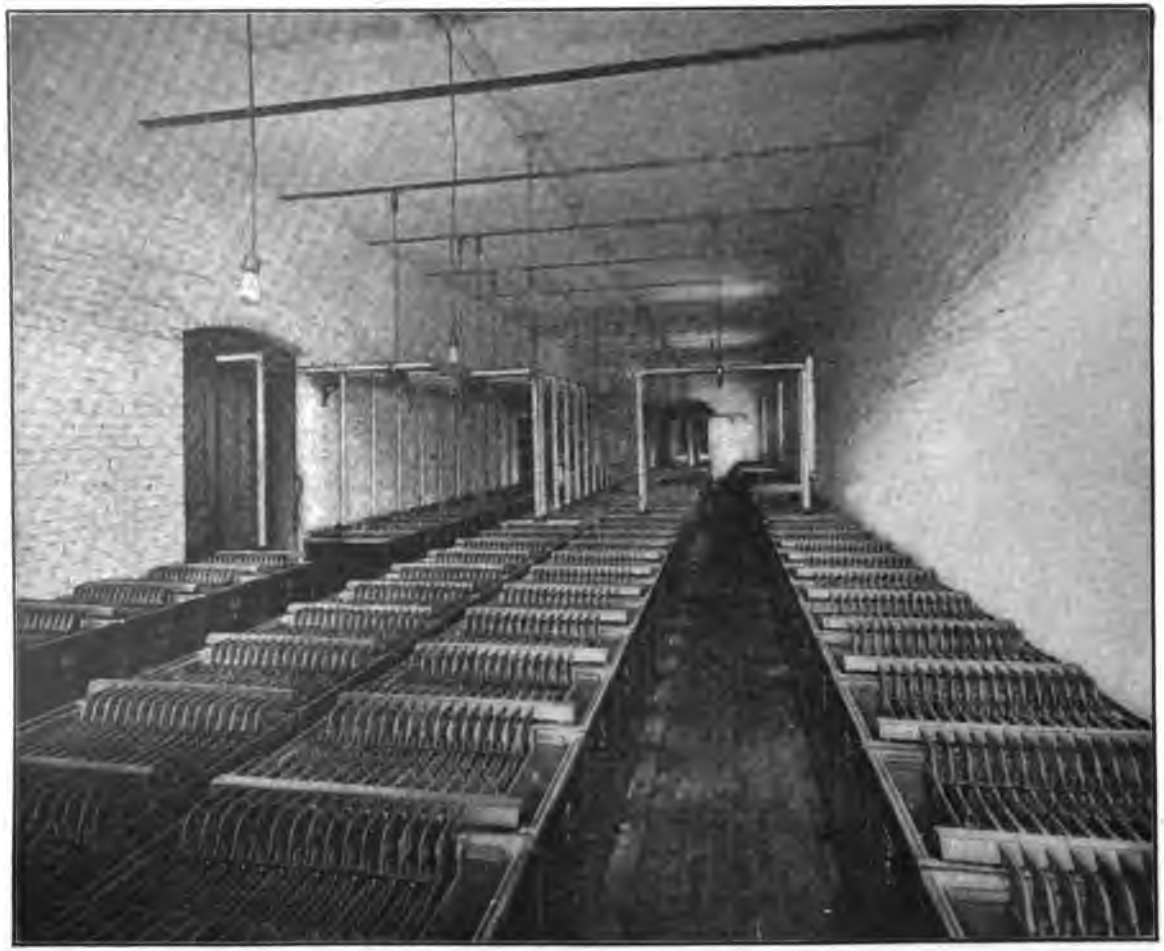
Solution.— In the formula $P = 30\ t$, the value of $t$ is 30. Hence $P = 30 \times 30 = 900$ pounds = total force required. Number of men required equals the total force divided by the force per man, or $900 \div 150 = 6$. Ans. 6 men.

## ALTERNATING CURRENT SYSTEM.

The alternating current is destined to become an important factor in the future development of electric railways. The facilities it offers for transmitting power with small losses over long distances, and the ease with which the voltage may be regulated to suit the conditions, make it indispensable for railway lines which are to be operated over distances exceeding ten or fifteen miles.

In the system which we will explain, called the alternating-direct system, the line voltage may be either that of the alternating current generator, or in especially long distance work it may be increased to any desired potential through raising transformers and again transformed down to the voltage to be used on the line. The alternating current is then changed to the direct current by means of a rotary transformer, direct current motors being used on the cars.

The rotary transformer or rotary converter combines in a single ring winding the armatures of a synchronous alternating current motor and a direct current dynamo. When supplied with an alternating current at proper voltage, it delivers a direct or continuous current at the required potential. Hence it is possible to secure the advantages of the alternating current for transmission from the source of power, and then to transform the electrical energy into the direct



AN INSTALLATION OF STORAGE BATTERIES BY THE ELECTRIC STORAGE BATTERY COMPANY.

current. Thus an alternating current reaching the rotary converter at say 400 volts, is transformed into a direct current and fed into the direct current feeders at about 550 volts.

In mechanical design the modern rotary transformer is similar to the modern direct current belted generator. It is usually multipolar, the field poles being laminated and rigidly held by a circular frame of cast iron. The armature coils and commutator bars are similar to those of a direct current generator, but the shaft carries in addition to the commutator, a number of collecting rings, similar to those used on an alternating current generator. The rings are connected at equi-distant points of the armature winding, to which the alternating current is supplied through the brushes and collecting rings. The machine thus runs as a synchronous alternating current motor. But the revolving armature winding generates an electromotive force, so that by connecting it to a commutator a direct current can be drawn from the brushes.

The direct current voltage depends on the arrangement of the armature winding and the width of the pole-pieces of the machine, but is always greater than the voltage on the alternating current side.

The distance between the sub-stations or transformer stations, is determined by the size of the direct current feeders and the loss permitted in the same. Thus with feeders designed for a drop in line potential of ten per cent with a transmission of ten miles, the sub-stations would be located twenty miles apart. If this distance be fixed at twenty miles and the alternating current loss in transmission be ten per cent, it then becomes an easy matter to determine the line voltage and size of conductors for the alternating current. The transmission of power from a single generating station for railway service by alternating currents, is practicable over distances up to 100 miles; thus generating stations on lines several hundred miles in length, would be about 200 miles apart.

The unsightliness of the overhead trolley system, and the difficulty that has been experienced in operating the underground trolley under all conditions of climate, have led many inventors to try to perfect some form of self-contained system of electric railways. The primary battery was tried at first, but was found to be too expensive, owing to the great cost of zinc, upon the consumption of which its power depends.

By the use of the storage battery practicable results have

Fig. 46.

been obtained. In the case of the primary cell in which the two elements have entirely distinct chemical composition, the discharge of the cell is accompanied by the destruction of one of the plates. In practical work it is impossible to restore the primary cell to an active state without renewing the zinc plate. In the secondary cell, however, instead of renewing the discharged plate, it is returned to its active state by reversing the chemical changes which accompanied discharge. This is accomplished by sending a current through the cell in the opposite direction to that of flow during discharge.

One of the roads of this character is the Chicago Electric Traction Co. running between Englewood and Chicago. In this system instead of placing the battery under the seats as has been the custom, they are carried on the truck supported on a tray between the two axles. A view of the truck with cells in position is shown in Fig. 46. The electrical equipment consists of seventy-two cells of battery, grouped in four series of eighteen cells each, which operate one fifty horse-power motor. Each cell contains nine plates 7″ by 14″, four positive and five negative, and weighs about 100 pounds. The E. M. F. of each cell is about 1.9 volts. Each group of 18 cells is pro-

vided with separate contact plates, which are connected by means of cables to the controller. The controller has five points and allows the combinations shown in Fig. 47, in which each set of 18 cells is represented by one cell. The motor is represented

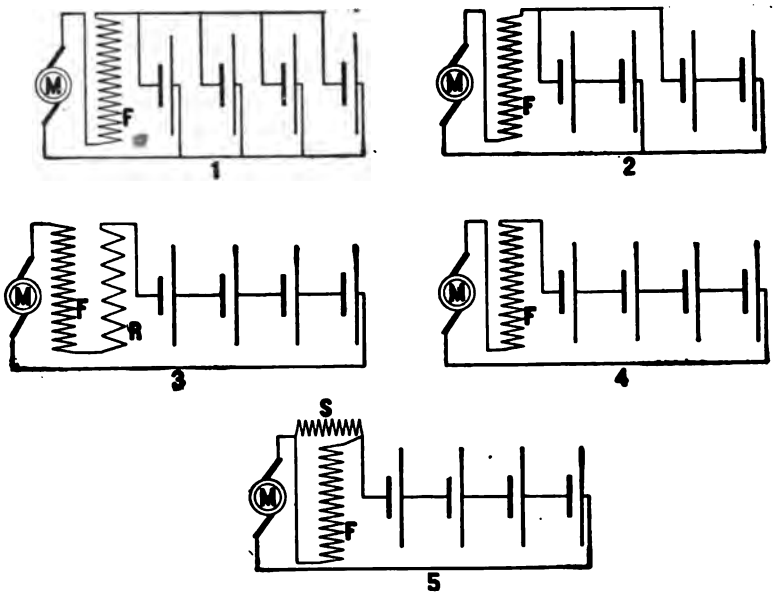



Fig. 47.

by *M*, the series field winding by *F*, a resistance by *R*, and a shunt by *S*.

The different combinations are as follows:

1. The four sets of batteries in parallel.
2. Batteries in series parallel, in sets of two.
3. Batteries in series with resistance.
4. Batteries in series without resistance.
5. Same as 4, but with field of motor shunted.

In systems where two motors are used, the foregoing combinations of batteries are augmented by series and parallel combinations of the motors.

Novel features have been introduced in order to facilitate the economical handling of the batteries. When a car returns for fresh batteries the discharged cells are removed by means of an electric elevator, carrying a small four wheeled truck, which rises

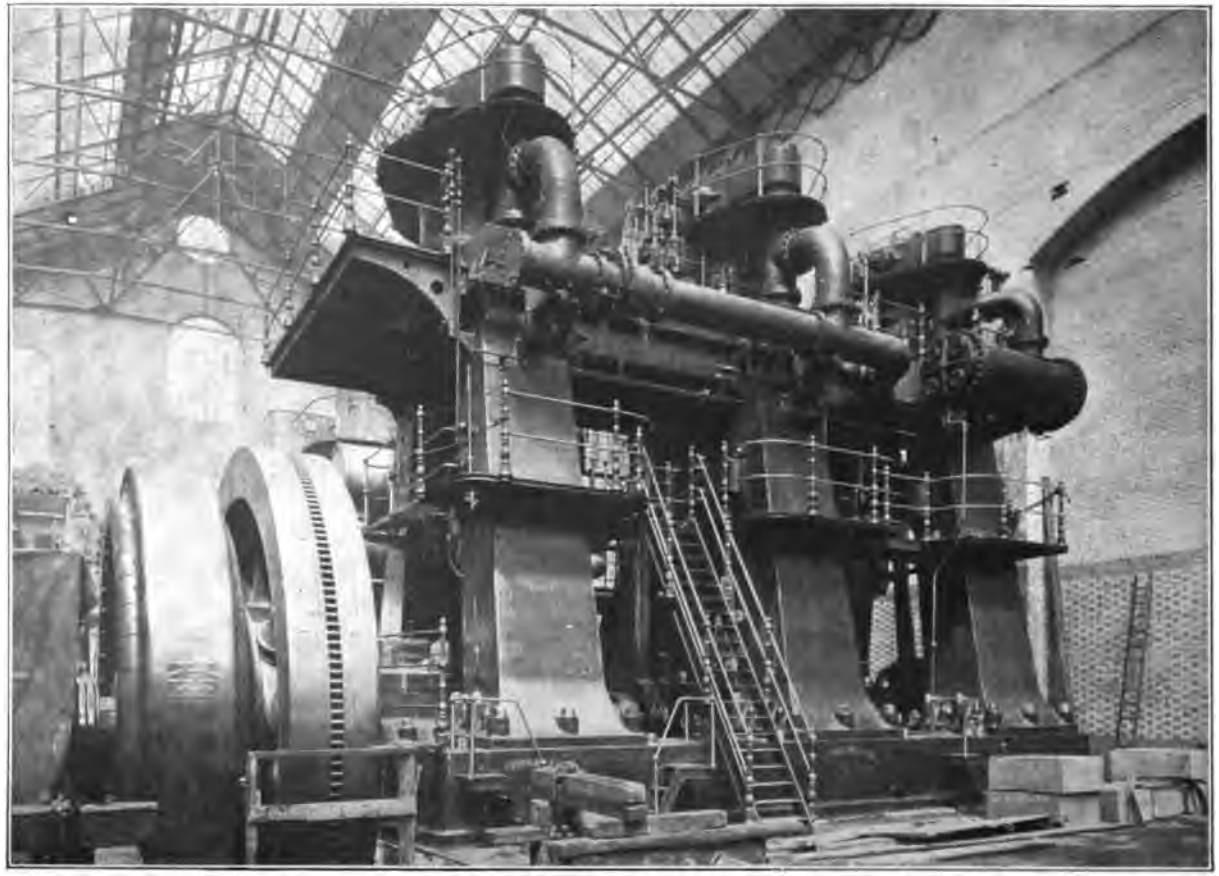
under the centre of the car. The cells are placed on this truck, which is then lowered and wheeled off to the charging room. A new set of batteries is then placed in position by the same machinery.

The principal difficulty encountered by roads using storage batteries has been in the electrical overloads, or undue and sudden calls for power upon the battery. These overloads tend to destroy the plates very quickly, which necessarily increases the cost of maintenance. If it were possible to run the cars upon a perfectly straight and level track, no such difficulty would be experienced. In practice, hills, grades, and curves cause excessive overloads, which together with over-discharging, have a ruinous effect upon the plates. The great weight of the batteries which must be carried by the car, is another serious objection.

The danger of over-discharge is now reduced to a minimum by the use of a special form of recording wattmeter. The essential requirement for such a storage battery meter is that it should run forward and backward with equal accuracy. Energy put into the cell is added to the reading of the meter, and energy withdrawn is subtracted, so that the reading of the meter at any time represents the available energy in the battery. In order to compensate for the loss in the cells the meter is made to run at a slower rate when charging than when discharging. The improvements that have recently been made in the manufacture of accumulators, and also under certain conditions, the economies which have been shown to be possible under such a system, may cause the extension of battery lines in the near future.

## UNDERGROUND CONDUIT SYSTEM.

The advantages which the underground conduit system present under certain conditions, make it one of the best systems to install in large cities where the original outlay for construction can be readily met by the traction company. Especially is this true when the complete metallic circuit is used and there is no return through the tracks. There is then no loss of current between wheel and rail or from bad bonding. The deleterious effects of electrolytic action upon gas and water pipes is eliminated entirely by this



**A SCOTCH ELECTRIC RAILWAY STATION SHOWING 5,000 H.P. ENGINE**

(By courtesy of the *Engineering Magazine*, New York and London)

method of construction. Also, the streets are not encumbered by poles and wires.

The conduit road recently installed by the Metropolitan Railway Company of New York City, represents the most improved type of underground trolley construction. The metallic circuit is used, the track rails not being used as a return, and the 500 volt system is employed. The conduit for the road is shown in Fig. 48. The positive and negative conductors are represented by *C C* and are held in place by insulating supports. The slot rails *S* and the track rails are laid upon and bolted to cast iron yokes, as

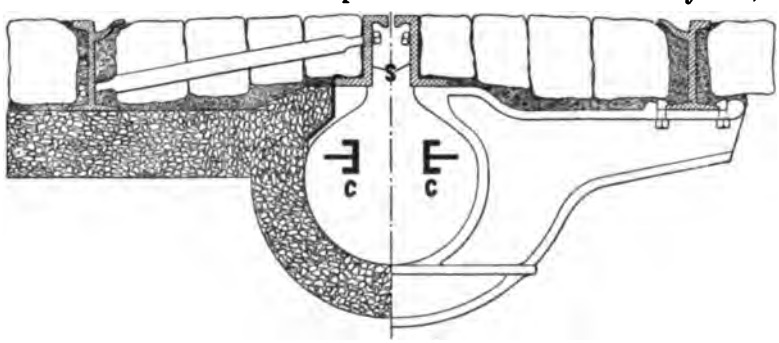



Fig. 48

shown in the right-hand half of the figure. The yokes each weigh 425 pounds, and are placed five feet apart on straight track. Iron sheathing extends between the yokes forming the conduit, and concrete is placed under and around this as shown in the left-hand half of the figure. The insulating supports for the conductors are placed 15 feet apart. A hand hole is placed above each insulator, permitting easy access in case of accident. Manholes are placed about 150 feet apart on straight track. For perfect drainage each manhole is connected to the sewer, and the conduits are pitched toward the manholes, so that water will not collect in any part.

At curves the ordinary yokes are used, but are placed nearer together as are also the insulators. Transition curves are used. At switches and crossings the conductors are interrupted, and the cars pass over these points by their own momentum. At such places the conducting rails are made flaring to make the entrance of the plough into them easier.

Special forms of crossovers and switches are used and the yokes for these are made of wrought iron pieces bolted together. The switch is arranged so that the switch tongue and slot rails are moved in unison by a lever.

The form of insulator used is shown in Fig. 49. It is made up of an inverted cast iron circular cup $5\frac{1}{2}$ inches in diameter, fitted with wings by which it is bolted to the slot rail. Within this cup is another of porcelain which is held firmly in the former by cement and which contains a $1\frac{1}{2}$ inch wrought iron shank supporting the conductor rail. The latter weighs 21 pounds to the yard and is of T shape. It is in 30 foot sections, bonded together by copper bonds. In these short sections the conductor can be slipped in the conduit from the hand holes without removing the slot rails.

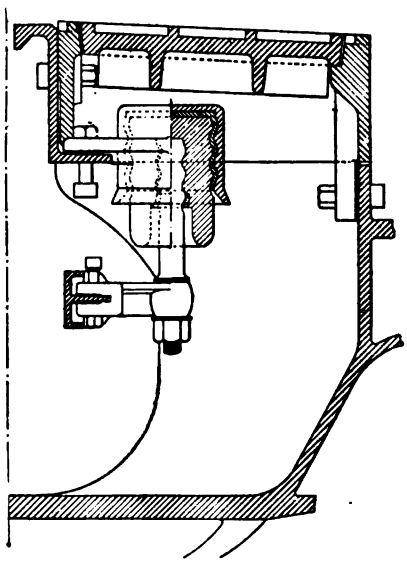


Fig. 49.

A side and end elevation of the plough is illustrated in Fig. 50. It has a total width at the slot level, indicated by the horizontal dotted line, of $\frac{9}{16}$ in. and immediately above and below this level, $\frac{7}{16}$ in. The wear at the slot rails is taken up by tempered steel wearing plates attached to the plough. The shank of the plough is made up of three steel plates. The conductors, which are wrapped copper ribbons, are carried down through the plough to the contact shoes of cast iron, connection being made between them by flexible cables. The tension is supplied by side steel springs which keep the shoes extended 8 inches apart when free, and 6 inches apart when in contact with the conductors. The pressure required to give good electrical contact has been found to be only about six pounds. The plough is supported on the car truck in a manner which allows certain flexibility in a vertical and transverse direction, but holds it rigidly in a direction longitudinal to the car.

All feed wires are carried underground at the side of the conduit in cement-lined ducts.

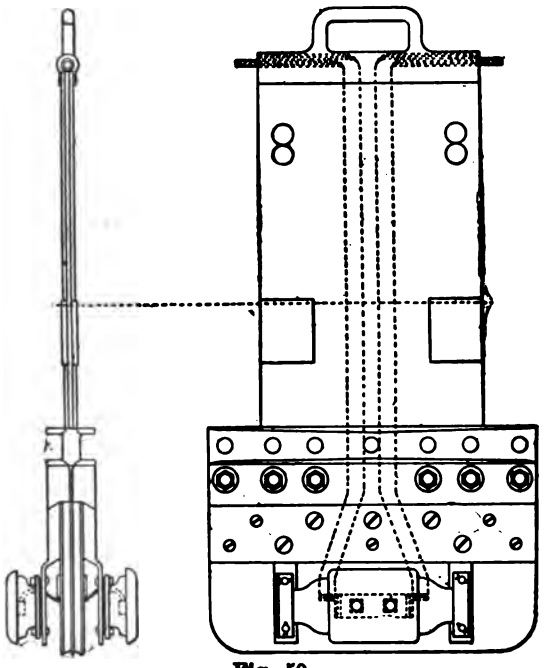


Fig. 50.

## THIRD RAIL SYSTEM.

Of the steam roads that have been recently equipped with the third rail, to supply power to electric locomotives, the sections constructed under the supervision of the New York, New Haven, and Hartford Railroad are undoubtedly of the best representative type. On the Nantasket Beach Branch both the trolley and third rail are used, the third rail beginning where the trolley ends.

There have been no mechanical troubles of importance with the overhead construction, but the difficulties of passing the heavy currents frequently called for by the cars, through the trolley wheels to the motor circuits, are most serious and burnouts of trolley wheels are not infrequent. There is also without doubt a considerable loss of power in arcing at the trolley wheels, when

going at such a high speed as these cars are capable of; even reaching a speed of a mile a minute.

In the third rail system the third rail, which supplies the current, is generally laid between the two track or service rails. The method of obtaining current from this rail by means of shoes has been found almost entirely satisfactory. The principal objection raised to this system (that of danger to the public), has been a theoretical rather than a practical one, partly because the voltage used is not such as is dangerous to life, partly because it is not easy to obtain a serious shock without special effort, and partly because the public have been carefully warned about the third rail, and have learned to respect it.

The engineering advantages of the third rail construction are

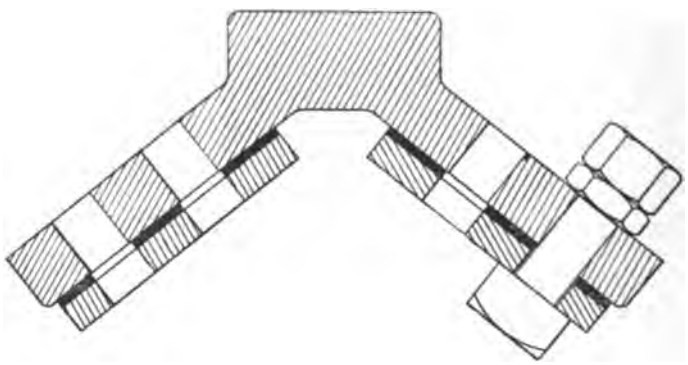


Fig. 51.

obvious. The rail can be easily and quickly laid, and so insulated from the ground that the leakage is very slight. This road has been run even when all three rails on one section were completely submerged in water for several hours. The third rail provides a conducting capacity for the current equivalent to a very large copper cable, so that on many light traffic lines copper feeder cables are not required. There is little sparking between the shoe and the rail, and no appreciable wear from friction. Altogether, the advantages of the third rail construction are such, that in one form or another it will doubtless become the standard method of conveying heavy currents in railroad service.

The rail used, as shown in section in Fig. 51, is one which is to a large extent self-protecting against rain, snow and ice, as the

tendency is to shed water to either side, leaving a fairly dry space immediately below the rail. This rail which is rolled in 30 ft. lengths and weighs 93 pounds to the yard, is mounted upon wooden block insulators, treated with a preservative and insulating compound. The blocks are fastened to the ties by dowels, and three blocks to each 30 ft. rail are ordinarily employed. The blocks are of such a length that the top of the third rail is held one inch above the top of the service rails, and the lowest part of the third rail is $1\frac{5}{8}$ inches above the ties. It is necessary to have the shoe on the car high enough to clear any special work along the track, and the third rail low enough to avoid reaching the metal parts of engines or cars passing over the road.

The bonding of the third rail, as shown in the same sectional view, consists of heavy wrought iron fish-plates between which and the rail, are placed sheet copper bond plates. These four plates, two of copper and two of iron, are firmly bolted to the rail by 16 bolts with lock nuts, and the entire double bond has a current carrying capacity which is in excess of that of the rail itself.

At switches and crossings there is a gap between sections of

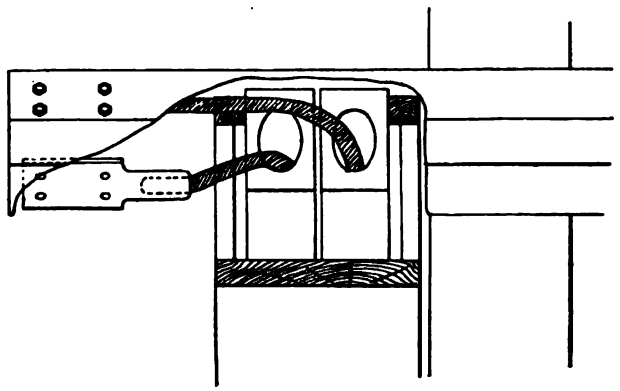


Fig. 52.

the third rail, but this gap is usually less than the length of a two car train, so that the shoe on the rear car will maintain connection with the circuit until the shoe of the motor car re-establishes connection at the end of the gap. When the gap is longer than the train, the current is shut off, and the train run over the gap by its own momentum. Beveled wooden blocks are provided at the

ends of the third rail so that the shoe will mount the rail easily.

Wherever the third rail is broken at switches and crossings, the electrical circuit is maintained by means of bare copper cables, drawn into creosoted wooden conduits filled with an insulating material made of residuum and asphalt. These conduits are placed in creosoted wooden troughs filled with the same compound and laid underground. The connections between the cables and the third rail at each end are made by a heavy copper connection which is thoroughly sweated and bolted to the rails. A plan of the cable connections at the rail is shown in Fig. 52, and a

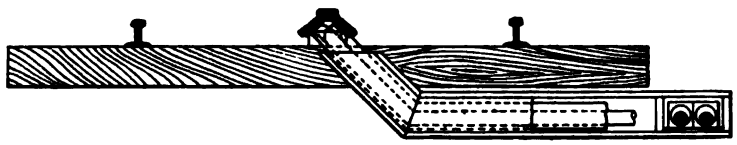


Fig. 52.

section of the track showing cable conduits is shown in Fig. 53.

The service rails are used as the return circuit. They are thoroughly bonded together by wedge driven copper leaf bonds, attached to the bottom flanges of the rails, and not to the web as in ordinary railway work.

**Car Equipment.** The cars used are 51 feet in length and have a seating capacity of 96 passengers. Each car in the train is electrically connected to the motor car, and each car also is equipped with a contact shoe, in order to bridge over gaps, and to provide against accident to shoes. The shoe is a cast iron plate 12 by 5 inches, and is suspended by links from a wooden insulated support fastened to the truck. The links are jointed in such a way as to give the shoe considerable flexibility. The motors used have a rated capacity of 125 H. P. each, two being mounted on one truck.

The brake equipment is a most important auxiliary apparatus in a system of this kind, where speeds from 40 to 60 miles per hour are made in regular service. The air brake has proved to be the most serviceable. A 10 H. P. motor is carried on one of the platforms of the motor car, and is put in connection with the engineer's valve of the Westinghouse air brake equipment as used on steam roads. The motor operates a compressor and is put in

operation and cut out automatically according to the requirements of the air reservoir. When the pressure falls below a certain point the motor is automatically started and when the required pressure is again reached the motor is cut out and the compressor stops. The automatic regulator may be adjusted to operate at from 45 to 100 pounds, and on a difference of pressure of from 5 to 7 pounds.

The system of car wiring is similar in most respects to that used in street cars. The path of the current is as follows: From the third rail it passes into the shoes and through a copper cable to circuit breakers (used instead of canopy switches), thence to the lightning arrester, through the choke coil, to a point where it divides into two paths, each going to a controller at opposite ends of the car, then to the resistances, back to resistance contacts in controllers, to motors and ground. All the switches, automatic circuit breakers, lightning arresters, etc., used with these trains are commensurate with the currents employed.

**Multiple Unit System.** In the operation of elevated railways and under other similar conditions, cars must sometimes be run in trains. This may be done by the use of a single locomotive drawing the necessary number of trailers, as in the Central London (underground) Railway, and in the Baltimore & Ohio Railroad tunnel in Baltimore, where heavy electric locomotives are used to pull the entire steam train through the tunnel.

With such an arrangement, however, it is not possible to obtain rapid acceleration of the train, and the necessary weight of the locomotive causes considerable vibration in the structure carrying the track. In the multiple unit system now coming into use, both of these difficulties are to a large extent removed. In this system each car of a train has its own complete electrical equipment of trolley (or contact shoe), motors and controllers; and the difference between the multiple unit train and one composed of ordinary motor cars is that the former contains devices designed to operate all the controllers at once — that is, to take the place of a motorman on each car.

Such a system might evidently be made by joining together with a suitable cable the corresponding points of all the car controllers. The train could then be operated from any one; but since this would involve the handling of very heavy currents

in the cables and the controllers, its cost would be excessive.

In the three systems used in the United States there is no main current carried between the cars of a train. The individual motor controllers are operated by a small *master controller* on the car platform, and the circuits of the master controller are carried by a *train line* to the mechanism by which the main controller combinations are made.

In the *Sprague system* the master controller operates a small pilot motor, which turns the controller cylinder, stopping automatically at the desired point. While the current is passing through the pilot motor, a solenoid spring brake is held inoperative, but when the current ceases, the brake at once clamps the armature shaft, stopping it almost instantly. This motor carries a double field coil, one half of which is used to run the motor forward, the other half serving to run it backwards.

The *Westinghouse system* revolves the controller by a ratchet and pawl mechanism driven by compressed air acting on a piston, as in the air brake. The air is admitted to the cylinder by valves which are in effect electromagnets operated from the master controller or *multiple control switch* on the car platform. Each stroke of the piston moves the ratchet wheel and controller one notch, and means are provided for giving the requisite number of strokes before the motion ceases. A separate cylinder is used to revolve the controller back to the off position. The current for the electromagnets is supplied by a small 8-volt storage battery carried on the car and charged while in service.

In the *General Electric Company's system* there is no main controller of the customary type. Its place is taken by thirteen separate switches, electromagnetically operated from the master controller. Since the series parallel controller itself is nothing but a combination of switches its operation will not be changed by separating it into its elements; and the various combinations of the thirteen individual switches, controlled by the master controller, make all the usual motor combinations. A series of cables connecting all the master controllers and sets of switches, and running the entire length of the train, insures that the same motor combination is made at the same instant upon each car.

All of the three systems described above have the necessary re-

versing switches and elaborate interlocking and automatic devices for cutting off the main current in case of accident to any of the circuits. Arrangements are also provided for cutting out any individual car whose apparatus may become disabled.

## LOCATION OF FAULTS.

As it is absolutely impossible to give complete directions for locating and remedying every fault that may occur in practical operation of street-car apparatus, we insert here a few of the most common difficulties, and the best way to remedy them.

**If Car Refuses to Start.**

1. Close lamp circuit; if lamps light up, the trolley and ground wires are all right.

2. If lamps go down or out when the controller is tried, poor contact in wheels and rails, or "dead" section of track is probably cause of trouble.

3. Try both controllers. If one works all right, the trouble may be due to an open circuit in the other. Thoroughly inspect tips, fingers and connections.

4. If fuse has blown, throw canopy switch and put in new one.

5. Look for broken brushes in motors, or bad contacts between brush and commutator.

6. There may be dirt between the wheels and rails. If such is the case, make connection with piece of insulated wire between wheel and track. If the section of rail is "dead," that is, not properly connected electrically with rest of track, make connection between wheel and next rail.

7. In winter, ice and sleet on the track or trolley wire may prevent the car from starting.

**Sparking on Commutator.** When sparking at the brushes is in evidence, it may be taken as a sign that something is wrong, as when everything about the motor commutator, armature, etc., is in good order, no sparking will be noticed. Some of the causes are as follows:

The pressure exerted by the spring in the brush holder may not be sufficient to keep brushes firmly against commutator.

If brushes are burned, or broken, renew them, or sandpaper them down to a good surface.

The commutator may be dirty, oily or worn out. Sandpaper, or renew it.

The commutator may have a flat bar, or one that projects beyond the others. Place the armature in a lathe, and take off a light cut, or smooth down with a file. Polish with fine sandpaper.

A steady flare at commutator may be due to the following:

1. A greenish flash that appears to run around the commutator is produced by an open circuit in the armature. It can be detected by the scarring of the commutator at two points diametrically opposite. These scars show which is the open coil. The best remedy for this is to replace the open coil by a new one. Temporary repairs can, however, be made by the aid of a "jumper." This consists in connecting the two adjacent burned bars by arching solder across. One "jumper" only is required for each open circuit.

2. Short circuits in the armature will be made evident by a jerky motion of the car, or by the fuse blowing out.

3. The magnetic field may be weakened through a short circuit or improper connections of the field coils. A short circuit in the field coils may be detected by means of a voltmeter, noting the potential drop across the terminals of the coils, the current being kept constant throughout the test.

**Lamps.** In case the lamps in the car do not light, examine each one to see if the filament is broken, and if each lamp makes good contact in the socket. Examine switch for loose connections and blown fuse. If the trouble is not found in this way, test the lamp circuit by means of a magneto bell, ringing from one socket to the next. This will locate the difficulty between two lamps by the bell not ringing and thus showing a broken circuit. Then examine these sockets and connections thoroughly. The light circuit wire may be broken off at the point of connection with the trolley or ground wires or at some other point.

**Failure of Brakes.** If the brakes fail to operate, the car may be stopped by the motors in two ways, which should only be used in case of emergency.

1. By reversing the direction of current in the field. See that the controller handle is at *off;* throw the reversing switch, and then turn controller handle to first or second notch, never beyond.

2. This method may be used whether trolley is on or off, and can be used to stop a car running away on a down grade. See that controller is at *off;* reverse the reversing handle; throw the canopy switch to *off*, and then bring controller handle to last notch and leave it there.

**Grounds.** The car will be rendered useless until repaired, and the fuse will generally be blown if the field or armature coils should become grounded.

**Bucking.** If, after running all right, a car suddenly begins to run with a jerky motion, the motors should be examined at once. This trouble is usually the result of a ground or short circuit in the field or armature. The injured motor can generally be located by the burning insulation, which may be detected when the trap door is lifted. Cut out the defective motor and run the car to the car-house with the other. Mud or water splashed upon the commutator, or a brush making poor contact will sometimes cause bucking. Oil on the shaft may work along to the commutator and cause a temporary ground.

**A Ground Detector.** A simple method of testing a motor for grounds is as follows: Connect six 110-volt incandescent lamps in series, one end being connected to trolley line through a suitable switch *B* and fuse, the other end being connected to ground. Between the fifth and sixth lamps from the trolley end insert a switch *A*. Tap the circuit between the fifth lamp and switch *A* with a test line long enough to reach inside the car to the motors. Also attach a test line to the ground connections below the sixth lamp. Now when switch *A* is open there will be approximately 550 volts between the two test lines. With the switch *A* closed there will be about 90 volts between the ends. This is a suitable voltage for testing between commutator bars for short circuits. Never use more than 300 volts pressure for this purpose.

When testing for grounds leave switch *A* open, disconnect the wires leading to the motors, then touch the motor terminals with the line leading from the fifth lamp, and notice if lamps light.

If lamps light when armature terminals are touched, the ground is either in the armature, brush holder terminals, or leads from terminal to brush holder. Remove both brushes and test again; if lamps glow, the ground is in the brush holder or leads. If lamps do not glow, touch the test wire to the commutator; the armature is grounded if they then glow.

If the lamps light when the field terminals are touched, disconnect the wires leading from one field coil to the next and test each coil separately until the grounded coil is located. If none of them show a ground, the trouble has been due to grounded connecting wires.

SECTION 5.

# CENTRAL STATIONS AND POWER TRANSMISSION.

## CENTRAL STATIONS.

**Location.** The location of a central station may sometimes be readily decided upon, or may involve considerable investigation. If water power is to be used, the location of the station is then confined to a certain point or to points where the power is available. If, however, steam power is to be employed, there are several factors which should be considered. Convenience of coal and water supply are of great importance. The station should, therefore, be located near a plentiful supply of water, and where coal may be conveniently received from the railroad or directly from coal vessels. The station should be located where the cost of ground is low, and it may then be built to cover a large area, permitting the engine, dynamo and boiler rooms to be on the same level.

The location of the station, especially for a low potential system, depends very much upon the district to which energy is to be supplied. A great aid in considering this is a map of the district, which should indicate, as nearly as possible, the amount of energy to be used at different points. This is determined approximately from a preliminary canvass of the district. If possible, the station should be centrally located, so as to have the line loss to the different points about equal. If a high potential system is to be used, the location of the station with reference to the receiving stations is less important. In fact, the system to be used may be determined by the site selected for the power house. All of the above details are largely dependent upon one another, and in the different cases some are of much more importance than others. The site to be selected in a given case is, therefore, largely a matter of judgment.

**General Arrangement.** This depends entirely upon the amount of ground space available. The ideal arrangement is to have the boilers, engines, etc. on the ground floor. This permits all parts to have a solid foundation and allows a convenient and simple arrangement of piping, belting, etc. With the present satisfactory arrangements for transmitting electricity long distances, allowing great range in the selection of a site, the number of large and convenient power stations is greatly increasing. In large cities, however, the size of the station is often limited by the high cost of land, and it is then necessary to place some of the apparatus upon the second or even third floor. A natural arrangement is to place the boilers on the ground floor, with the engines

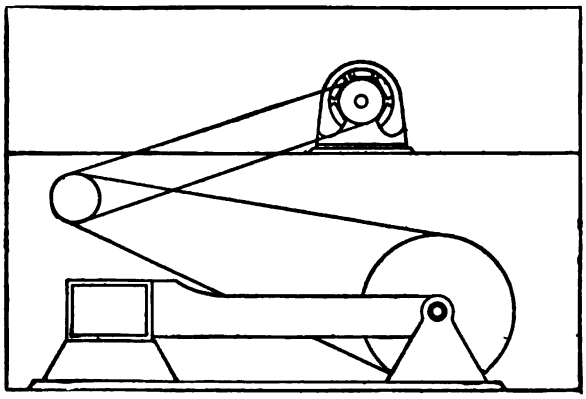


Fig. 1.

and dynamos above. Such an arrangement has the serious objection that excessive vibration of the machines will always take place unless they are located on a solid ground foundation. The engines and dynamos are, therefore, usually located on the ground floor and the boilers above. Sometimes the dynamos, if in small units, are on the floor above the engines. The satisfactory arrangement of the belting is then a matter of some difficulty. If the belts are vertical, or nearly so, but little power can be transmitted unless there is considerable tension on the belts, and this would involve objectionable loss by friction. A common arrangement is to run a belt from the fly-wheel of the engine diagonally across to a line shaft from which several belts lead to the dynamos above.

This arrangement is shown in Fig. 1, there being horizontal distance enough between the shafts to enable the belts to run properly.

Belted machines, in central stations, are now largely confined to those supplying a constant current to series arc lights. Such machines have comparatively small capacity owing to the fact that if one alone supplied a large number of lights, the voltage would be unsafe. As each lamp requires about 50 volts, machines are made to supply only from 50 to 100 lights, which gives a voltage of from 2,500 to 5,000. Belting is still common in stations installed some years ago, and even in modern stations when the company still has in its possession a number of machines of too much value to be discarded. Direct and alternating current dynamos having constant potential, are now installed in large units and almost always directly connected, there being either one or two dynamos to each engine. The most convenient arrangement of engines and generators is to place them side by side in a single line.

In order to reduce complication as much as possible and to increase the efficiency of the machines, the number of units now usually installed is small. It is, of course, important that there should be enough spare apparatus to prevent crippling the plant in case of the breaking down of one element. If the units are too few in number, it may be difficult to fully load the machines during considerable periods of time, and this causes a sacrifice in efficiency. For isolated plants or small stations, there should be from two to four units, and for large stations from four to eight units. The best number for any particular station will, however, depend largely upon local conditions.

**Buildings.** In former times it has been common to use a building for the central station which was originally erected for some other purpose. This involved adapting the location of the apparatus to the form of the building, and often resulted in inconvenient and complicated arrangements. The size of stations has now grown to such proportions and the requirements for simplicity, convenience and safety are so important that buildings are now almost invariably erected especially for the purpose. Such a building should be simple, substantial and designed to reduce the

danger from fire to a minimum. It should also be well lighted and ventilated. Usually but one story, provided with a basement, is all that is required.

The best type of station has brick or stone walls with an iron roof, but small stations are often built of wood throughout. A wooden floor is preferable to any other kind for the engine and dynamo room on account of not giving up much grit or dust to collect on the machines, and also on account of affording some protection from receiving a shock. The boards should be blind nailed to further reduce the possibility of receiving a shock, and it is sometimes necessary where very high voltages are used, to take special precautions by insulating that part of the floor near the dynamos and switchboard.

The boiler room should be separated from the dynamo and engine room by a fireproof partition, and to reduce still further the danger from fire as well as to better exclude the dust and smoke from the machines, the boilers are sometimes placed in a separate building. Provision should also be made for the convenient and expeditious handling of coal and ashes. It is usually important to arrange the main rooms so as to allow a considerable increase in the size of the plant with but little inconvenience. To assist in placing the engines and dynamos as well as for ease in moving the machines when repairs are to be made, a traveling crane is frequently installed. Although this involves considerable expense, it is however, of the greatest advantage even in stations containing but few units.

If a storage battery is to form part of the station, a special room must be devoted to it, with a view to prevent the acid fumes from corroding the apparatus of the dynamo and engine room.

**Foundations.** A very important feature of the central station is the foundations for the machinery. The foundation required for machines of different makes varies considerably and is sometimes built and guaranteed by the engine or dynamo manufacturer. The makers are familiar with the requirements of their own machines, and should always be consulted as regards the foundation. An inexpensive machine often requires a comparatively expensive foundation. When it is necessary to prevent the trans-

mission of vibration, as in the case of isolated plants located in office buildings, the main foundation is sometimes built upon a cushioning layer of sand, hair-felt, or asphaltic concrete. If the ground upon which the foundation is built consists largely of soft earth or sand, no cushioning is required.

The depth and nature of the foundation depends largely upon the character of the ground on which it is to be built and upon the size of the machinery. The foundation usually consists of concrete and brickwork, the bricks being laid in cement mortar. If the machine is provided with a cast iron base, this may be placed directly upon the brickwork. Otherwise the foundation should be capped by a slab of stone which not only serves to hold the foundation together, but also forms a level surface for the machinery. The latter is securely held in place by foundation bolts.

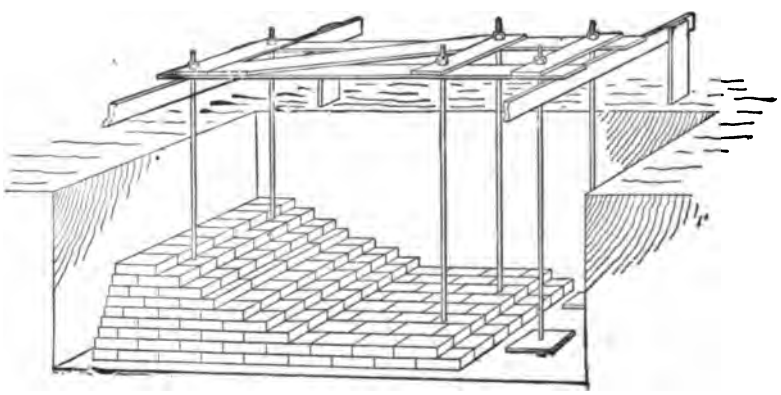


Fig. 2.

These pass down through the foundation and are held firmly by plates at the bottom. The bolts are supported during the laying of the foundation, and given their proper relative positions, by a wooden template built for the purpose. Such a template is shown in Fig. 2.

**Boilers, etc.** Boilers and their accessories are considered in other parts of this work, and only special features will here be considered. The boilers used for central stations are usually of the water-tube or fire-tube type. The former type is much more generally used, on account of its safety, ease of

repair and handling in sections and on account of its being well adapted to the exacting demands of central station work.

The importance of preventing any interruption of service has often led to the installation of a duplicate set of high pressure steam piping. This practice is now adopted in but few cases as it is found that with a proper arrangement of piping and valves, a plant can be made perfectly reliable in this respect. Piping can now be constructed much more substantially than in former years and with proper arrangement any one part may be cut out of the system and repaired, without interferring with other portions. Water should not be allowed to collect in the steam piping and to prevent this the piping is often inclined towards the engine, the water collecting in the separator or steam trap inserted near the engine. The best method, however, is to run a small pipe directly beneath the main pipe, which is connected to it at intervals of a few feet. The water will then collect in the small pipe and may be led back to the boiler.

Steam piping should be securely supported and placed upon rollers to allow for expansion. If expansion is well provided for, strains and leaky joints will be greatly reduced. By covering the pipes with some poor conductor of heat such as mineral wool, asbestos, hair-felt, etc., the loss by radiation may be reduced to one-fourth or one-eighth as much as occurs without any covering. All high pressure steam piping should therefore be covered with such material.

Brass feed piping is preferable on account of its great durability, freedom from corrosion and low cost of repairs. A check valve should be placed in the pipe between the feed pump and boiler to prevent the water from flowing back into the pump. Also a stop valve should be inserted between the check valve and boiler to allow the check valve to be repaired with but little inconvenience.

In addition to each feed pump an injector is usually supplied to be used when the pump is out of order. A constant feed supply is then assured.

Many modern plants are equipped with electrically driven air and water pumps, etc., but there is some doubt as to whether this proves more economical than the use of steam.

**Engines.** Compound condensing engines are now more commonly installed in central stations than any other form. Preference is given to as large engines as are practicable, on account of the less cost per horse-power and the increased efficiency of large engines over small ones. Triple expansion engines are not as much favored as formerly, since it has been found that a compound engine will give in most cases nearly as high efficiency as a triple expansion; also the first cost and cost of maintainance is less. In exceptionally large sizes triple expansion engines are favored. Large compound engines are sometimes made with two low pressure cylinders as the diameter of a single cylinder would be excessive.

The difficulty of obtaining a plentiful supply of water for condensing purposes has caused recently the adoption of cooling devices. The water from the condenser is cooled by intimate contact with the air and used over and over again. The loss of water by evaporation is only from 5 to 10 % which must be supplied from some outside source. Such a cooling device may consist of a **cooling tower** or **table.** A tower consists of a series of vertical tubes or sheets usually within a wrought iron frame, through which air is forced by blowers and down which flows the water from the condensers. The water coming in contact with the air is cooled, accumulates at the bottom of the tower, and is again brought in contact with the exhaust steam.

A cooling table, which is used where ground space is available consists of a series of boards laid gridiron shape, through which the water from the condenser drips to a tank at the bottom. The water is thus cooled by contact with the air, and is then available for use in condensing. These devices, especially the cooling table, are inexpensive and may result in a saving of at least 15 % in fuel.

**Connections.** Dynamos of large capacity are almost always directly connected to the engines. The first cost of the machines is greater when direct coupling is used, but the compactness and simplicity of direct coupling are often of greater importance. The dynamo armature is commonly keyed directly to the shaft of the engine. The usual arrangement is to extend the engine shaft and mount the armature upon it, a third bearing being added outside the dynamo.

**Belting**, although not nearly as much favored as formerly, is in some cases far more preferable than direct coupling. The cost of installing direct coupled machines may be as much as four times that of belted machines which would accomplish the same work. In such extreme cases the adoption of belting would of course be preferable. Belting has the advantages of being inexpensive, provided there is ample space; almost any speed ratio may be obtained, the machines being independent are readily accessible, and the dynamo is well insulated.

## SWITCHBOARDS.

For the safe and convenient handling of the electrical apparatus the switches, measuring instruments and other auxiliary devices are assembled upon the switchboard. Switchboards are usually made of marble or slate, in slabs from one to two inches thick. As these materials are good insulators and non-combustible, the controling devices may be mounted directly upon them, which permits a simple and convenient arrangement. Besides being a good insulator marble has the advantage of being impervious to moisture, and has a fine appearance. Slate is stronger and tougher than marble but conducting veins are sometimes present which may cause serious trouble. Slate is often marbleized or coated with a surface resembling marble. This not only gives it a better appearance but prevents it from absorbing moisture.

As it is inconvenient to handle large slabs of marble or slate, the switchboard is usually made up of several sections or panels. These are held together by iron framework and supported by iron standards and braces.

The switches, instruments, etc., should be arranged in a simple and systematic manner. All conductors should be supported rigidly and far enough apart and from the metal framework to prevent accidental contact or the current from arcing across. The path of the current should be short and the crossing of wires avoided as much as possible. The wiring and connections are usually made on the back of the board, only the switches and instruments being mounted upon the front.

The switchboard should be located in a position to allow full

view of the different machines and not in a position where the instruments would be exposed to an accident, as by the breaking of a belt. In large stations the switchboard is sometimes located in a gallery overlooking the different machines. It must be placed so that the danger of communicating fire to adjacent combustible material is slight. There should be about two feet of clearance between the board and the floor or ceiling. If the connections are upon the back, all parts should be accessible, but if the wiring is entirely on the face the board may be placed against a brick or stone wall.

Switchboards have been made of wood, but this is not a good plan on account of danger from fire. If wood is used, the switches, fuse-blocks, etc. should be mounted on insulating and non-combustible bases such as porcelain, marble or slate. Only a skeleton frame of wood is then required to support this apparatus. The wooden frame should be filled to prevent the absorption of moisture.

**Switches.** Good design and construction of a switch are very important. A triple pole main line switch is illustrated in Fig. 3. The base is usually of slate or marble. Ample contact between the blades and clips is necessary, and the clips should exert considerable pressure against the blades when the switch is closed. To insure good contact the clips are sometimes made up of several thicknesses of metal or divided into several fingers. This increases their flexibility and allows good adjustment in case the blades are not perfectly aligned. The clip should be shaped so that on opening the switch, the contact is broken along the whole length at the same instant. Otherwise, the small portions in contact at the final breaking would be rapidly burned away by the arcing at those points.

Fig. 3.

Quick-break switches are constructed so that the switch is opened abruptly by the action of a spring. The time of arcing is thus made as brief as possible and the damage reduced. A spring

for such use should not carry any current, as in that case it would soon lose its tension. The best switches have all conducting parts made of copper. Brass is also used, but its conductivity is considerably less than copper, and the size of its parts must be correspondingly greater.

Switches are called single, double or triple pole, depending upon whether the switch has one, two or three blades. Switches are also called single or double throw. The switch illustrated in Fig. 3 is called a single-throw switch. If, however, the switch is provided with a double set of contacts, so that it may be closed in either of two directions, it is called a double-throw switch. Fig. 4 illustrates a double pole double-throw switch. A switch of this kind is useful when it is desired to switch either one of two circuits on to a machine.

**Fuses** are used to protect circuits from currents which are above their safe carrying capacity. They consist of a section of some easily fusible metal inserted in the different circuits, and of such size that an unsafe current melts them and breaks the circuit. For use with moderate currents the alloy comes in the form of wire on spools, but for large currents the fuse consists of a strip of the alloy provided with copper terminals. The fuses are made for a certain carrying capacity, which depends mainly upon their cross section, and fuse when the current is a certain per cent. in excess of this. This is usually stated at 25% or 40%. The fusing point depends, however, upon many other conditions than the cross section, such as length of the fuse, temperature of surrounding air, its position, whether vertical or horizontal, and whether enclosed or not. Only a

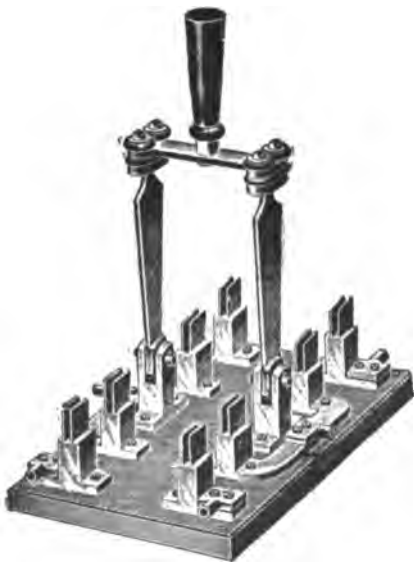


Fig. 4.

moderate amount of dependence can, therefore, be placed upon the melting of the fuse when the current reaches a certain value. A fuse link is illustrated in Fig. 5, and a fuse block in Fig. 6. The dimensions of fuse links are such that they may be fastened securely between the terminals on the fuse blocks.

**Circuit-Breakers** have recently come into extensive use, especially upon switchboards. They serve the same purpose as fuses but are much more reliable. The current passes through the coil of an electro-magnet, which may be arranged to automatically open a switch when the current strength reaches a certain value. In addition there is an attachment by which the current strength, at which the circuit-breaker will act, may be regulated. There is also some device for reducing the damage from arcing as much as possible, when the circuit is opened. The switch is provided with a handle so that it may be opened by hand, and when circuits carrying heavy currents are to be opened, the circuit-breaker is always used, the ordinary main switch being more often used to close the circuit. Circuit-breakers are commonly used in circuits carrying heavy currents, and fuses in branch circuits carrying the smaller currents. Where a circuit is likely to be frequently overloaded, as in electric railway work, circuit-breakers are indispensable.

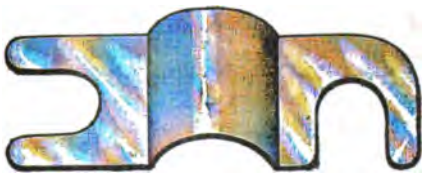


Fig. 5.

Fig. 6.

**Ammeters and Voltmeters.** It is customary to provide one ammeter on the switchboard for each dynamo, so that its output at any time may be evident. Station ammeters are usually provided with a separate shunt through which the main current is passed. The leads to the ammeter from the shunt terminals take only a small amount of the total current, but the ammeter scale is graduated to indicate the full current. This permits a simple arrangement of the heavy

conductors on the switchboard and a considerable saving in copper, which could not be possible if the full current was passed through the ammeter. Instead of a special shunt, a certain length of the conductor itself is sometimes used for this purpose, the ammeter leads being connected to the conductor a short distance apart.

Only one voltmeter is necessary for a series of machines as it is not important to observe the voltage of all the machines at one time. The two voltmeter leads are connected to a voltmeter switch, which may be turned to several different positions. Potential leads from the different machines are connected to this switch, and when the voltage of any one machine is desired, the switch is turned so as to bring the terminals of the voltmeter leads into connection with the terminals of the potential wires from that machine. Another method is to connect the potential wires of the different machines to a plug switchboard, and the voltage is obtained by inserting plugs connected with the voltmeter into the different receptacles to which leads from the machines are joined. An additional contact is usually provided, which is connected with the ground and used for testing the insulation of the different circuits and machines.

Ammeters and voltmeters for switchboard use are provided with large plainly-marked scales so they may easily be read at a distance, and should be always well lighted by incandescent lamps.

**Regulating Resistance**. A field rheostat connected into the shunt field of the dynamo for the purpose of regulating the voltage is also mounted upon the switchboard. One rheostat is required for each machine. These rheostats usually consist of German silver wire connected to a series of contact points, contact being made with them by a sliding arm. The amount of resistance inserted in the shunt circuit of the dynamo at any time is determined by the position of the sliding arm. The rheostat is usually mounted upon the back of the switchboard; connection being made by a shaft with an operating wheel on the face of the board. A plate is usually placed above this controlling wheel to indicate in which direction the wheel should be turned either to raise or lower the voltage. The rheostat is sometimes mounted directly

upon the face of the board. It should be located at a sufficient height from the floor to allow its convenient operation.

**General Arrangement.** There are three general classes of switchboards:

1. For direct current low-potential circuits.
2. For alternating current high-potential circuits.
3. For series arc-lighting circuits.

The size as well as the general arrangement of a switchboard depends upon the number of machines, number of circuits supplied and system used.

A switchboard for a **direct current constant-potential system** is illustrated in Fig. 7. This is designed for three dynamos to be operated in parallel and to supply seven circuits. At the foot of the board are the three main switches for connecting the dynamos to the bus-bars which extend along the back of the board. Above them are the controlling wheels of the three rheostats which are in this case mounted upon the back of the board. A little above the center of the board are the switches for the separate supply circuits. At the top of the board are one voltmeter and three ammeters; one for each dynamo. The voltmeter switch is shown above the middle supply switch. This is supplied with four pairs of contact points. Connection is made with one pair to the positive and negative bus-bars, and with each of the others to the leads from the three machines. Connection is made to the dynamo leads outside the switches so that the voltage of the machines may be ascertained whether they are connected to the bus-bars or not.

The three single-pole switches near the main switches are for the equalizing connection. When these are closed the brushes of the three machines from which the series coils start are all connected, which is necessary to maintain them at a uniform voltage. The equalizer bar appears in addition to the two bus-bars upon the back of the board. If for any reason the voltage of one machine becomes less than that of the others, current will flow through the equalizer to that machine and cause its voltage to be raised. When all machines have the same voltage no current will flow through the equalizer. Instead of having a double and a single-pole switch, the two are often combined into a triple-pole switch,

the middle pole being for the equalizer. With large machines and where the switchboard is some distance from the dynamos, much better regulation is secured by running the equalizer directly between the machines, the equalizer switches being mounted upon pedestals near them.

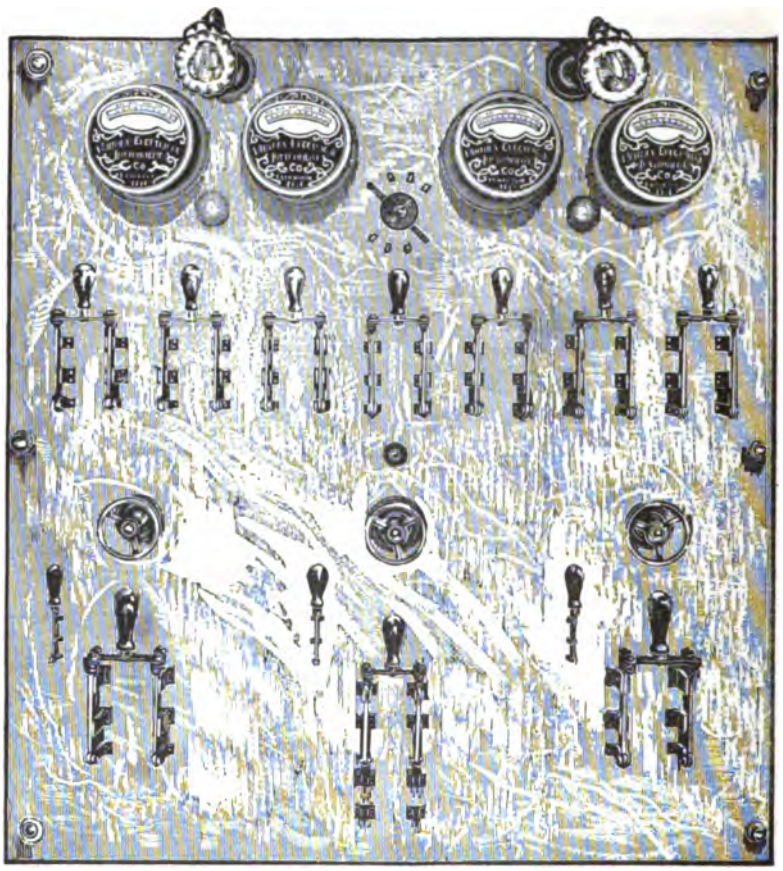


Fig. 7.

Switchboards for **alternating current** systems are in general similar to those for the direct current. On account of the high potentials commonly used, it is of great importance that there should be no charged metal parts exposed on the face of the board so that the chance of obtaining an accidental shock will be reduced.

For each generator there are usually two rheostats mounted upon the switchboard, one of which is connected in the field circuit of the alternator and the other is connected in the field circuit of the direct current exciter. A special form of high potential switch must be used, as the breaking of a high potential circuit would otherwise cause dangerous sparking, especially if inductance is present in the circuit. Single-pole fuses are commonly used which allows the two branches of the circuit to be widely separated from each other.

The alternating current voltmeter is generally arranged to give the voltage existing upon the secondary supply circuits and not the voltage of the alternators. A small transformer is therefore usually mounted upon the back of the switchboard, which reduces the generator voltage in the same ratio as the transformers on the circuits. The voltmeter is connected to the secondary of this small transformer.

The general arrangement of a switchboard for alternating currents depends largely upon whether the alternators are to be operated in parallel or upon separate circuits. For separate running, switches are arranged so that any feeder may be transferred to any dynamo. The larger the number of machines the greater will be the complication of the feeder panels. A convenient arrangement for changing the load from one dynamo to another is to have the leads from all the dynamos extend to each feeder panel; the load may then be transferred from one dynamo to another by means of plug connections and a switch for making the transfer from one dynamo to another.

When the dynamos are to be operated in parallel the wiring and connections may be simpler, but there is required the synchronizing device and its connections.

With a two-phase machine using four wires, the two wires of each phase are treated just as two wires of a single-phase circuit. Each of the two circuits, or phases, is provided with an ammeter and one voltmeter is arranged so that it can be connected to either circuit by a plug switch.

Switchboards for arc-lighting circuits are of an entirely different nature from the above. The arrangement is much simpler and much less apparatus is required. Generally the only appara-

tus appearing on the switchboard is one or more ammeters, the dynamo and circuit terminals and the connecting cables. As the capacity of arc dynamos is usually small, there commonly are several of these machines in a station and it is necessary to arrange the switchboard so that any circuit may be transferred to any dynamo.

Fig. 8 shows a common and convenient arrangement of a switchboard for arc lighting. This is arranged for eleven dynamos and eleven circuits and is provided with two ammeters. The dynamo terminals (*A* to *L*) are shown on the lower part of the board, the upper row being the negative and the lower row the positive terminals. The line terminals (*1* to *11*) occupy the upper part of the board, the top row being negative and the lower positive, as in the case of the dynamo terminals. Each terminal has two sockets and by means of cables any circuit may be connected to any dynamo. Either ammeter may be connected into any circuit when it is desired to test the strength of the current. The cables are highly insulated and their tips arranged to secure good contact with the sockets both mechanically and electrically. The figure shows circuit *11* connected to dynamo *L*, circuits *8* and *10* in series and connected to dynamo *K*, and circuit *7* connected to dynamo *G* with an ammeter in series.

An arc light circuit should *never* be opened when the machine is running as the inductance present would cause the production of a very high E. M. F.; this might pierce the insulation at weak points and would also cause a damaging arc at the point where the circuit was broken. It is often necessary to transfer a circuit from one machine to another, to connect circuits in series, insert or take out the ammeter, etc., and this must be done without opening the different circuits. This is accomplished by the use of double contacts at each terminal. As an illustration suppose it was desired to disconnect circuit *8* from circuit *10* and connect it in series with circuit *11*. Circuit *8* would first be short-circuited by connecting a cable from negative terminal *K* to negative terminal *10*. The two cables to circuit *8* could then be removed without affecting the lights in circuit *10*. To insert circuit *8* in series with circuit *11*, the negative terminal *11* would be connected with positive terminal *8* and negative terminal *8* with negative termi-

nal *L*. Circuit *8* is then short circuited by the cable from negative terminal *11* to negative terminal *L*. Upon removing this cable therefore, circuit *8* will be thrown in series with circuit *11*. If it were desired to insert the right-hand ammeter into circuit *11*, a cable would be connected from the positive terminal of the ammeter to positive terminal *L* and one from its negative terminal to positive terminal *11*. By removing the cable connecting positive terminal *L* with positive terminal *11*, the ammeter will be

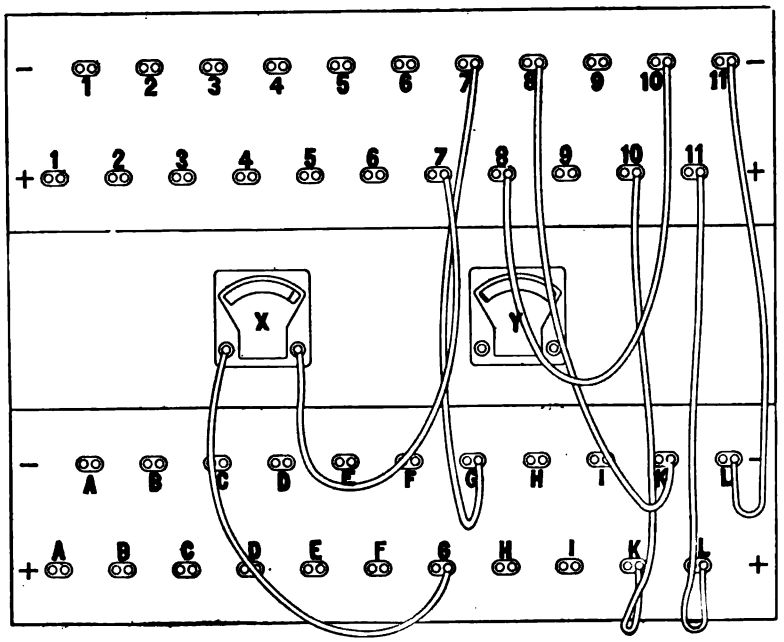



Fig. 8.

inserted. If it were desired to disconnect the left-hand ammeter from circuit *6*, a cable would be used to connect positive terminal *G* with positive terminal *7* and the cables to the ammeter removed.

**Lightning Arresters.** Where circuits extend some distance from the station, it is important that lightning arresters should be used to protect the electrical apparatus from lightning or atmospheric electricity. Such protection is of course only necessary for aerial lines. The chance of damage by lightning depends upon the length of the circuit, its height above ground, and the

location. Some localities are subject to damage by lightning to a much greater extent than others. In Colorado for example, this is a question of considerable difficulty and much more protection is there necessary than in less mountainous countries.

A lightning arrester not only should conduct lightning discharges to earth, but should also avoid any interruption of the service. The early forms of arresters consisted of a ground connection from the line excepting for a small air gap. This gap would prevent the normal current from leaking to ground, but a lightning discharge would leap the gap and pass to ground instead of passing through choke coils, coils of the machines or even long lines of straight wire. A serious objection, however, to this type of arrester when used on lines carrying heavy currents, was that the dynamo current followed the lightning discharge across the air gap and by maintaining the arc caused an excessive current to flow from the machine. This would melt the dynamo fuses or cause further trouble and thus interrupt the service.

A large number of arresters have been devised with a view to preventing this latter difficulty. At first the continuation of the dynamo current across the gap was prevented by placing fuses in the lightning arrester circuit. However, when these were once melted there remained no protection from further lightning discharges until they were replaced. A large number of arresters were then devised with a view to permitting a number of discharges to take place without requiring any attention and also to prevent the dynamo current from continuing in the path of the lightning.

Among such arresters are those which automatically interrupt the arc and then immediately adjust themselves for another discharge by means of moving parts. A number of these depend upon the rapid expansion of the heated air to move certain parts and thus lengthen the gap. The parts then return to their former position by the action of gravity after the passage of the discharge.

Arresters without moving parts are more satisfactory and often more reliable. The Thomson arrester has no moving parts and depends for its action upon the "magnetic blow-out." An electromagnet through which the current from the dynamo passes, is arranged so that a strong magnetic field is created at the air

gap. The arc is prevented from continuing by the repellant action of this field upon it and is thus forced to points at a greater and greater distance from each other until it breaks.

Another successful arrester without moving parts and adapted for alternating currents is that invented by A. J. Wurtz. This consists of a number of cylinders, each measuring one inch in diameter by three inches long, which are placed side by side with a gap of $\frac{1}{64}''$ between them. The arrangement is shown in Fig. 9, the cylinders being held in place by marble slabs across the ends. The middle cylinder is connected to ground *G* and the outside ones to line *L*, one arrester being sufficient to protect both sides of the circuit. The dynamo is indicated at *D*. The cylinders are knurled which allows a discharge to pass readily from the outside cylinders to ground, sparks appearing between the cylinders. The arc is not, however, continued by the dynamo current owing to the nature of the metal of which the cylinders are made. The arc established by the lightning discharge is quickly extinguished. This is probably due to the fact that some metals, notably zinc, mercury and antimony, upon the passage of a discharge will suddenly evolve such a large amount of vapor as to extinguish the arc. The cylinders are made of zinc alloyed with a small quantity of copper. If the cylinders burn away much at the gaps they may be turned so as to present new surfaces.

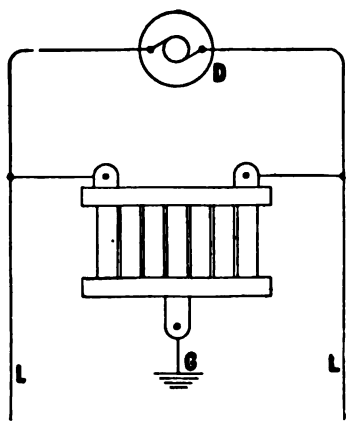


Fig. 9.

A type of arrester adapted especially for railway circuits and also invented by Mr. Wurtz, is that in which the arc which tends to form, is confined within a small space. There being no room for vapor the arc is prevented from forming.

Lightning arresters are usually located where the conductors enter the station, either before or immediately after entering the building and before reaching any apparatus. Each line should be protected and for very long lines additional arresters should be

placed at intervals along the line, especially at exposed places or where any special apparatus is located.

It is very important that there should be good ground connection with the arrester, and that the conductor to ground should be as short and straight as possible. Rich soil gives the best ground connection. Clay, rock, sand, gravel, dry earth and pure water are not suitable. For the purpose of obtaining good ground connection it may be necessary to locate the arresters at some distance from the station, in which case it would be necessary to construct a lightning arrester house.

A ground connection for a bank of station lightning arresters may be made as follows: A hole about six feet square is dug directly under the arresters until permanently damp earth is reached. The bottom is then covered with two feet of crushed coke or charcoal and over this is placed a tinned copper plate about five feet square. A No. 0 ground wire should next be soldered across the entire surface of the ground plate and then covered with two feet of crushed coke or charcoal. This allows the surface drainage to increase the natural dampness of the earth. The hole should then be filled in with earth and settled by the use of running water.

For line arresters a hole two feet in diameter may be dug until permanently damp earth is reached. A gas-pipe eight or ten feet long with open ends is then driven down, and a solid brass plug is screwed in the upper end, to which the ground wire of the arrester is soldered. The hole is then filled in with crushed coke or charcoal.

## MANAGEMENT OF DYNAMOS AND MOTORS.

**Dynamo Selection.** So many dynamos and motors are manufactured differing largely in important and unimportant features, that it is not easy to select the best dynamo for a certain kind of work. Special types of dynamos are made to fulfil certain conditions of service but some general instructions may be given applicable to almost all cases.

The material entering into the construction of a dynamo should not only be of the best grade, but the machine should also be constructed in a substantial and careful manner. If the

machine has a good finish it will show the presence of small amounts of dirt and there will be more of an incentive on the part of the attendant to keep the machine clean. The design should be as simple as possible and the more the parts are accessible the greater will be the ease in making repairs. Numerous small parts are objectionable and any delicate construction should be well protected.

There should be provision for the easy removal of the armature which should be constructed so as to allow the coils to be easily replaced. Special sizes or designs of machines are undesirable on account of the difficulty in duplicating parts. The regulator should be capable of governing the voltage or current of the machine within close limits.

**Dynamo Installation.** In selecting the place for a dynamo care should be taken to see that it is clean and dry; a cool location is also desirable. There should be plenty of room to take out the armature and for easy access on all sides of the machine.

Machines over 25 H. P. capacity should be provided with a stone or brick foundation, the depth of which depends mainly upon the nature of the ground and size of the dynamo. For the purpose of insulation, it is customary to place dynamos upon a wooden base-frame. This should be filled with oil or varnished to prevent it from absorbing moisture and thus destroy its insulating property.

With belted machines short or vertical belts should be avoided in order to eliminate slipping as far as possible. A distance of at least three or four times the diameter of the larger pulley should be allowed between the pulley centers. The proper width of belt to use is a little smaller than the face of the dynamo pulley; usually about one inch smaller. The driving and driven shafts must be parallel, and the centers of the two pulleys in a line at right angles to the shafts. If, on slowly turning the machine by hand, the belt runs in the middle of each pulley, the machine is properly placed. If the belt runs to one side, however, the machine should be moved accordingly. The strain on the belt should be only sufficient to prevent slipping. The length of a new belt should be only long enough for the nearest position of

the machine to the driving shaft. As the belt becomes longer by use, there will then be ample room for moving the machine on the rails or base plate and so secure the proper tension. In order to give a uniform wear upon the commutator and bearings, the armature shaft usually has an end play of a quarter of an inch or more.

In assembling a machine great attention should be paid to the following:

1. Care in handling all parts to avoid injury to them.
2. Thorough cleanliness of all parts.
3. The correct assembling of all parts and making of proper connections.

The armature is packed separately except in the case of small machines, and should be handled with the utmost care. Iron clad machines will stand considerable rough usage, but even then care is necessary with regard to the end connections and commutator. The armature should preferably be supported by its shaft, but whenever placed upon the ground or floor it should rest upon a cushion of cloth. A sling should be used in handling a heavy armature which should be looped over the ends of the shaft, and to prevent the ropes from bearing against the ends of the armature or commutator, a board of proper length should be inserted between the two ends of the sling.

The utmost cleanliness of the bearings and of surfaces making electrical or magnetic contact is especially important. In assembling, a photograph of the machine and diagram of connections will prove useful.

**Starting.** Before starting the dynamo a thorough and careful inspection of all parts is necessary to see that all connections are correctly and firmly made, and that nothing is in position to interfere with the free rotation of the armature. The brushes should be properly placed and exert sufficient pressure on the commutator to give good contact. Carbon brushes require more tension than those of copper. It is advisable to turn the dynamo armature slowly before actually starting, noting if it turns easily and if the brushes make proper contact at all parts of the revolution. If the bearings are provided with rings to give free circu-

lation of oil about them, it should be seen that they work smoothly and accomplish their purpose.

When the dynamo is actually started up it should, if possible, have its speed very gradually increased, so that any faults which may develop can be remedied before any damage results. Also, if copper brushes are used care should be taken to avoid reversal in direction of rotation.

In such an event the brushes might trip on a commutator segment and thus be broken. It is desirable to start the machine upon open circuit and afterwards add the load.

The starting of direct and alternating current motors is considered in other parts of this work. Before throwing the main switch for starting a motor, one should always be sure that the starting resistance is included in the armature circuit. This should gradually be cut out as the motor comes up to speed. Automatic devices which cause the rheostat handle to assume the starting position whenever the motor is stopped are very desirable, and in some cases required by insurance regulations.

**Stopping.** In stopping a dynamo or motor it is undesirable to throw any switch carrying a heavy current. If a single dynamo is supplying the whole current to a circuit or to several circuits, the machines should be allowed to gradually come to a stop and the main switch then opened. This avoids the breaking of a circuit carrying a large current and consequent arcing at the switch. If any other dynamo or storage battery is on the circuit, a different method is followed.

If a constant potential dynamo were gradually stopped while still connected to the circuit with others, it would form a short-circuit for the other machines; hence in stopping such a machine it is necessary to first disconnect it from the circuit. By means of the field rheostat the voltage of the machine to be disconnected is lowered, until its ammeter shows that it is supplying no current. It should then be disconnected from the circuit and stopped.

A constant potential motor is stopped simply by throwing its main switch, if possible when under no load. The rheostat handle, if not automatic, is then turned to the starting position.

Constant current dynamos or motors, being connected in series, must first be short-circuited by closing the main circuit

around them, after which they may be disconnected. Special forms of arc circuit switches accomplish this by a single throw of the handle. These machines will not be injured if stopped when still connected to the circuit, as the current strength is constant.

If there is any chance of the armature reversing in direction of its rotation before coming to a full stop, the brushes, if copper, should be raised just before this is likely to occur. The brushes should never be raised from the commutator when the machine is under load or when the fields are strongly magnetized.

After the machine is stopped it should be cleaned of all dirt, dust, or superfluous oil, particular attention being paid to the commutator and brushes. A dynamo can be much more readily cleaned after a run, when it is still warm, than after it has become cool.

**Running.** Considerable attention should be given to a new machine when it is first operated. Afterwards it will require but little attention. A new machine should be operated at first only under a light load. After thus running in a satisfactory manner for a few hours, the machine may be fully loaded. The belt, which is likely to stretch considerably at first, should be fairly slack to begin with and gradually tightened. This preliminary run allows the bearings and belt to get into good working order.

After a dynamo is once placed in good working condition, its durability and freedom from troubles is largely determined by the care it receives. This care amounts principally to seeing that the bearings are well oiled, that the brushes maintain good contact with the commutator, that the latter is worn smoothly, and that the machine is kept clean. The bearings and field coils should be occasionally tested with the hand to see that they are not overheated. Upon the first appearance of any overheating, excessive sparking, etc., the trouble should be immediately remedied, for if allowed to continue, it would probably develop to a harmful extent.

Overloading should always be avoided if possible. Most machines will stand overloading for a *short time* without injury and some machines for a considerable length of time. It is very objectionable however, and is one of the main causes of faults developing in machines.

Care should be taken at all times to avoid personal injury. When a complete circuit is formed through the body or any part of it with a live wire, the person experiences a shock. Therefore when handling a dynamo which is in operation the person should not stand upon or be in contact with any good conducting medium. Also different parts of the machine should not be touched at the same time, and the practice of using only one hand at a time in order to avoid shocks, is a very good one. With high potential circuits special provision should be made for safety, such as the use of rubber gloves, tools with insulated handles, and insulating mats.

An oil-can made of non-magnetic material such as brass, should be used to avoid its being attracted and caught in revolving parts.

## CAUSES AND REMEDY OF FAULTS IN DYNAMOS.

**Failure to Build Up.** A number of causes may prevent the field magnets from attaining their full strength, which is commonly the reason of failure to build up. A primary cause is absence of residual magnetism which is shown by a piece of iron not being attracted when brought near the pole-pieces when the dynamo is not running. This may be remedied by exciting the field coils from an outside source, or, if the demagnetization is due to the influence of an adjacent machine one of the machines should be turned half way around or the magnetism of the poles reversed.

If the field coils are connected so as to oppose each other, there will be no resultant magnetism and therefore the dynamo cannot generate its full E.M.F. Nearly all machines have successive poles of opposite polarity, hence a fault of this nature can be detected by testing the polarity by means of a compass needle. If the same end of the needle is attracted by successive poles it shows that they oppose each other. In such a case the connections of the field coils requiring a reversal of polarity should be changed.

An open circuit in the machine will of course prevent the flow of current and therefore the field magnetism will remain weak. This fault may be located by a careful inspection of the machine or by testing the parts separately by the *fall of the poten-*

*tial* method. A short circuit in the machine will also prevent it from attaining its full E.M.F. Such a fault may be located in the same way as an open circuit.

If the connections are such that the current generated by the armature and flowing through the field coils opposes the residual magnetism, the latter will be destroyed and no E.M.F. generated. A reversal of residual magnetism will not remedy the fault, as the direction of the current generated by the armature will also be changed and destory the magnetism as before. This trouble may be overcome by changing the direction of rotation of the armature, or by reversing *either* the armature or field connections. An incorrect position of the brushes may prevent a dynamo from attaining its full E.M.F. In the case of a shunt dynamo, building up may be prevented by a short circuit in the external circuit or by having too great a load in starting. In the case of a series dynamo, building up may be prevented by the resistance of the external circuit being too great.

**Sparking.** This is a common trouble and owing to the large number of causes to which it may be due, it is one of the most difficult to locate.

An incorrect position of the brushes will cause sparking, but this is readily overcome by shifting them to their proper position. It may also be due to the brushes not being an equal distance apart along the circumference of the commutator. This can be ascertained by counting the number of commutator segments between the forward edges of successive sets of brushes, which number should be the same in every case.

A cause of sparking which is evident upon inspection is a rough or uneven commutator, or poor brush contact. A small amount of roughness in a commutator may be eliminated by use of a fine file or sand-paper. Emery cloth should never be used for this purpose, as the emery particles remain in the metal and cut both commutator and brushes. If the commutator is very rough, uneven, or eccentric it should be carefully turned down in a lathe and smoothed off. Small particles of copper which may have become lodged in the mica insulation during the process should be picked out. Poor brush contact may also be due to an uneven brush or the presence of dirt. A carbon brush

can be beveled to fit the commutator by placing it in its position and inserting a strip of sand-paper between it and the commutator and drawing it back and forth, face against the brush. The brush then receives the same curvature as the commutator.

Sparking will result from an excessive flow of current, whether this excess is either continuous or intermittent. Overloading of a machine or a line short-circuit may cause continuous sparking. This cause will be evident by the excessive heating of the whole armature. A short circuit, or a grounded circuit in the armature will cause an excessive current and consequently sparking. These faults may be located by the fall of potential method. In order to have a complete short-circuit within the machine, two grounds are necessary.

If the field magnetism is weak the armature will cause more than its normal amount of distortion of field and sparking will result. A condition of this nature may be brought about by a short circuit, open circuit, or grounds in the field coils, as well as by an incorrect connecting up of the coils.

**Heating.** Heating as well as sparking may develop from a large number of causes and also may occur in any part of the dynamo. This should be carefully tested by occasionally applying the hand. If the hand can be held against any part of the machine for a few moments without feeling uncomfortably hot, then the machine is not seriously overheated. There is, however, considerable variation in the sensitiveness of the hand to heat, and the sensation depends also upon whether the part touched is a good or poor conductor of heat. The field coils, for example, will feel cooler than the pole pieces even if at the same temperature.

It is sometimes difficult to locate the cause of excessive heating, owing to the fact that the heat may be rapidly transmitted from one part of the machine to another, causing the whole machine to be apparently uniformly heated. In order to locate the source of the trouble it is often necessary to allow the machine to remain inactive for a few hours to permit it to come to a uniform temperature, which will be that of the surrounding air. The machine may then be run on no load for a few minutes and afterwards examined. As the heat will not in this case have had time to be transmitted to other parts of the machine, the part

where the overheating first appears will be the hottest.

Excepting the case of hot bearings the heating is almost invariably due to an excessive current. Most of the causes of sparking at the commutator will therefore also cause overheating. Heating of the armature may be due to overload, or reversed or short circuited coils; in the latter case after the test one or more of the armature coils will feel hotter than the others. Where large conductors are used on the armature the heating may be due to eddy currents within the conductors themselves. A hot armature may also be due to the insufficient lamination of the core.

Overheating of the field magnets may be due to a short circuit within them or to their not having a sufficient resistance. In the case of series coils, however, their resistance may be too great. Insufficient lamination of the pole pieces or field cores may also cause overheating. Excessive sparking, poor connections or short circuit of the commutator may be the source of overheating. Also the brushes may not have sufficient carrying capacity.

Any of the following may cause overheating of the bearings: lack of oil, rough shaft or bearings, dirt in the bearings, bearings too tight or out of line, a bent shaft, overload, or belt too tight.

**Motor Faults.** All or most of the preceeding applies to motors as well as to generators. Serious trouble is sometimes met with in starting a motor. If, upon closing the motor switch the motor refuses to start, the switch should at once be opened; otherwise an excessive current will flow which may not only melt the fuses but may also burn out the armature. In the case of constant current motors however, no special harm is done as the current has the same value at all times. After having made an examination and removed the probable trouble, the switch should again be closed but immediately opened if the motor does not start, when further examination should be made. Large overload is one of the causes which may prevent a motor from starting or cause it to stop. The same effect is produced by great friction in the bearings or the rubbing of the armature against the pole pieces, etc.

The motor may not start on account of wrong connections or an open circuit at some point. An open or short-circuited field

circuit will be shown by the poles being but weakly magnetized. This may be tested by holding a piece of iron near the pole pieces. No current passing through the armature will be apparent by an absence of spark when the brushes are lifted from the commutator. The trouble may be due to no current on the supply circuit, open switch, melted fuses, brushes out of contact with commutator or loose or broken connections or a broken wire.

**General.** No general directions can be given to cover every case that is likely to occur but the above refers to the common difficulties and together with the use of a little thought and careful examinations should enable one to locate almost any difficulty. Special types of machines are subject to troubles peculiar to them alone, but directions for such machines usually accompany their shipment.

## MANAGEMENT OF ACCUMULATORS.

**Installing Cells.** The cells are sometimes placed upon the floor of the battery room, and sometimes arranged in tiers upon substantial shelves. Each cell should be accessible and allow the easy removal of its parts. The cells are sometimes insulated from each other by being supported on glass insulators.

As acid fumes are given off from the cells, it is necessary to take precautions against its chemical action upon any wooden or iron construction in the room. Iron must be coated with an acid-proof paint and the wood may be varnished or treated with paraffin. Tiled walls and floors are very desirable since they are unaffected by the acid fumes and may be easily washed.

As the E.M.F. of each cell having lead plates, is about 2 volts, a large number are joined in series in order to secure the voltage commonly required. The general connections therefore consist in connecting the positive terminal of one cell to the negative of the next, and so on. All connections should be firmly made (best soldered), and all contact surfaces scraped clean.

The electrolyte consists of an acid solution, formed by adding sulphuric acid to water. Water should never be added to sulphuric acid on account of the violent chemical action which takes place. The density commonly used is 1.2, the proper strength being determined by the use of a hydrometer. The density of the

electrolyte falls to some extent after it is added to the cell, and also varies according to the amount of charge it contains.

**Charging.** The rate of charging any particular type of cell is usually specified by the manufacturer and depends mainly upon the size of the cell. It is desirable, however, to charge a cell for the first time at a much lower rate than that which is to be regularly used, and this consequently requires a much longer time. For example, if the normal current in charging is 10 amperes, the current used for the first time should be about 5 amperes. The voltage required for charging is higher than that given by the battery, and usually is regulated to give the desired current strength. If the voltage is kept constant in charging, the current will decrease in strength as the battery becomes more fully charged.

There are a number of ways in which the amount of charge at any time may be determined. In the case of a lead battery the E.M.F. of each cell gradually rises about .5 volt. When discharged its voltage is about 1.9 volts and when fully charged is about 2.4 volts. The density of the electrolyte may be about 1.25 when the cell is charged, and 1.2 when discharged, there being a difference of about .05. The amount of charge may also be determined by measuring the input and output of the battery by means of a recording wattmeter and making allowance for losses. When the battery is fully charged bubbles are given off, and the electrolyte appears to boil. Also when discharged the positive plates have a reddish brown color and when charged are almost black; and the negative plates change from a light to a dark slate color.

**Discharging.** Upon discharging a battery the same changes occur as in charging but in the reverse order. Usually a higher rate of discharge is allowed than in charging but an excessive flow of current may prove injurious. The discharge is usually continued to about 1.9 volts, but the voltage falls rapidly near this point.

If a charged accumulator stands idle for any length of time, the amount of charge will gradually decrease. This loss is not serious, however, unless the interval is greater than ten hours. As accumulators are charged during light loads and discharged during heavy loads, the interval of disuse is usually less than ten hours.

**Troubles in Accumulators.** If an accumulator is discharged beyond proper limits, or left discharged for a long time, the plates may become *sulphated.* This is also produced by the use of too strong an electrolyte. The plates then become coated with a whitish scale, which is objectionable for several reasons. The most serious results are the reduction in capacity of the accumulator and the deterioration of the plates. If the *sulphating* is considerable the plates must be replaced by new ones. A small amount, however, may be removed by carefully scraping the plates and afterwards slowly charging the cells. The cells should afterwards be discharged only partially and then fully recharged. By repeating this a number of times the sulphate is gradually removed.

If the cells are too rapidly charged or discharged, *buckling* or *warping* of the plates may take place. This trouble is also one of the results of sulphating. The part of the plate covered by the white sulphate is rendered inactive; hence during action, the unaffected part will cause unequal expansion or contraction of the plates and may cause warping. If but slightly warped the plate may be straightened by placing it between boards and subjecting it to great pressure.

The plates may become short-circuited by fragments of the plates loosening therefrom and extending across from one plate to the next. This disintegration of the plates may be caused by sulphating, sudden expansion or contraction and buckling.

## POWER TRANSMISSION.

The losses in transmission of power by electricity may be divided into three general divisions; the loss in making the transformation into the electrical form of energy at the generating station, the loss in transmission along the line and the loss in transformation at the receiving station. The line loss will now be considered.

**Line Loss.** The line loss is obtained directly from Ohm's law, $I = \frac{E}{R}$, or $E = R\,I$. If the potential loss in the line, or *drop* is known, the power lost in the line is found by multiplying the drop by the current passing in the wire, since power is the product of E.M.F. and current, or $E\,I$. From Ohm's law the drop is equal to the product of the resistance and current ($R\,I$) and therefore the lost power is equal to $R\,I$ multiplied by the current, giving $I^2\,R$. The loss depends therefore, upon the square of the current. That is, if the current passing through the wire is doubled, the lost power instead of being doubled is made four times as great; or if the current is tripled, the loss is made nine times as great. This loss is dissipated as heat throughout the length of the wire.

It therefore follows that in transmitting electrical energy, the smaller the current the greater will be the efficiency of transmission, providing the same size and length of wire is used.

Since power is the product of the E.M.F. and current ($E\,I$), a given amount can be transmitted either by having a low E.M.F. and large current, or having a high E.M.F. and small current. In transmitting 10,000 watts, the voltage could be 100 and the current 100, or the voltage could be 1000 and the current 10. The power lost in the line however, is widely different in these two cases if the same size and length of wire is used in each. The value of the current in the former case is ten times what it is in the latter, but the loss in the former case would be one hundred times what it would be in the latter. Where a large amount of power is to be transmitted, it is evident that this loss assumes considerable importance. Furthermore, in order to keep this loss

low, it is important to use the highest permissible voltages for long distance transmissions.

Since by doubling the voltage, the loss is decreased one-fourth, or by tripling the voltage the loss is decreased one-ninth, it is evident that if the percentage loss is kept constant in each case, the resistance of the line can be made four times as great when the voltage is doubled, or nine times as great when the voltage is tripled. The size of the wire could therefore be reduced one-fourth or one-ninth in the respective cases and the cost of the same greatly reduced. This saving in the cost of the line or in the line loss, shows the advantage of using a high voltage in power transmission over any considerable distance.

**Voltages in Use.** Practical considerations necessarily limit the extent to which the voltage may be raised and successfully utilized. With alternating current systems, about 50,000 volts is at present a limiting value, and this can only be used by the utmost care in the insulation, special types of insulators being necessary. At present there are about twenty plants installed, working on a voltage of 20,000, but above this the work has been largely experimental. The difficulty in insulation rapidly increases above this figure. Systems operating at 10,000 volts are plentiful.

In the case of direct current systems, the voltage is limited by the nature of the apparatus used. In the series system for arc lighting voltages of from 3,000 to 5,000 are not uncommon. The highest working voltage of constant potential machines of the direct current type is about 500 or 600 volts. Above that figure the difficulty of keeping sparking at the commutator within proper limits cannot readily be overcome. In the three-wire system the voltage between the outside wires may be 1000 or 1,200, if 500 or 600 volt dynamos are used.

**Direct and Alternating Current Systems.** Power transmission by the direct current system, owing to the comparatively low voltage obtainable, is out of the question for long distance transmission. Its field is confined to transmissions over short distances and to special cases in which the alternating current has not yet proved serviceable. An example of such is found in electric railway work.

The high voltage which is obtainable by alternating current

machines, and the ease with which the voltage can be raised or lowered on the line by means of transformers, renders it highly desirable for long distance transmission. It is also adaptable to both lighting and power, the induction motor having now been brought to a satisfactory state of art. The greatest objection to the induction motor lies in its power factor, or the ratio of the watts actually used to the apparent watts. If a number of such motors are in use on a system and they require the apparent watts supplied to them to be one-fourth again as much as the true watts consumed, it follows that the line loss will be correspondingly increased as well as the necessary station capacity. The gain in operating motors on alternating current circuits however, more than offsets this disadvantage as well as minor ones.

**Alternating Current Systems.** The most direct arrangement for a system using the alternating current would be to generate the current at the desired voltage, transmit the same, and apply it to motors or lamps at the receiving points without the intervention of transformers. With this arrangement the voltage of the line must necessarily be limited to that of the receiving apparatus. The great advantage of the alternating current system would in that case be lost.

The system next in order is that in which the voltage of the generator is the same as that of the line and comparatively high, but in which step-down transformers are used at the receiving points, to reduce the line voltage to that required by the receiving apparatus and which safety demands. The voltage of such a system is limited only by that which it is practical to generate directly. The voltage when this system is used is seldom less than 1000 volts. The highest voltages are obtainable from machines having stationary armatures and are in the neighborhood of 5000 volts. With higher voltages the amount of insulation necessary becomes so large, that the extra cost of the machine is greater than is the case when transformers which raise the voltage are used.

Where very high voltages are desirable the voltage of the generator is raised by means of step-up transformers, is transmitted, and then lowered at the receiving stations. This system is used for transmissions over very long distances and where it is desirable to have the line loss small.

**Use of Polyphase Systems.** The above considered single phase systems are less common for long distance power transmission than polyphase systems. One great advantage of the latter is their value for operating motors. The use of polyphase windings, moreover, also increases the capacity of the dynamos and betters their regulation.

Two-phase and three-phase systems are the only polyphase systems which have become common. In the case of the two-phase system a complete circuit per phase is usually installed, making four conducting wires. The three-phase system may have three complete circuits or, as is almost always the case, these may be combined and but three conducting mains used.

In a three-phase system having three wires, the weight of the copper in the line for the same line efficiency and at the same voltage, is only 75 per cent. of that required for a direct current or any alternating current system using two wires per phase. That is, if a certain amount of copper is necessary in a direct current system, single-phase, two-phase with four wires, or three-phase system with six wires, then the three-phase system having three wires would require but three-fourths of that amount. This great advantage of the latter system makes it especially desirable where a small line loss is necessary.

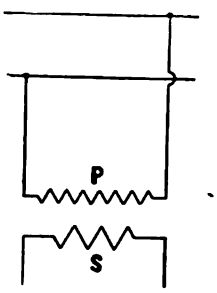


Fig. 10.

**General Connections.** The methods of connecting transformers in polyphase systems is simple. In the single-phase system the terminals of the primary coil are connected to the line, and from the secondary terminals extends the wires to the receiving apparatus. This method is illustrated in Fig. 10. The primary coil is represented by *P* and the secondary by *S*. The method of connecting the two-phase system having four wires is illustrated in Fig. 11. Two transformers are used, and as far as the connections are concerned they are the same as for two single-phase systems. Each pair of wires is independent of the other and there are, of course, four secondary wires. Lamps may be connected across the two leads from each secondary, but all four wires are used for operating motors. In the two-phase system

using three wires, one being common to both phases, two transformers also are used. The primary coils are connected in series and the point of union connected with the common wire, as shown in Fig. 12. The secondary coils are also connected to each other and from their union extends the common wire of the secondary circuit. Lamps may be connected between the common

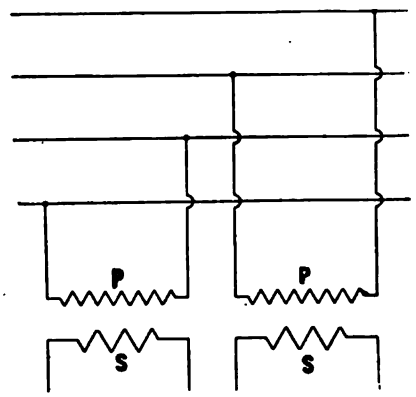



Fig. 11.

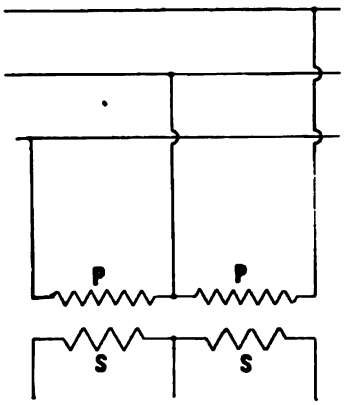



Fig. 12.

and either of the outside wires; the three wires, of course, are necessary for connecting motors.

In the three-phase system three transformers are used. The method in which the primary and secondary coils are connected is shown in Fig. 13 for the star, and in Fig. 14 for the mesh arrangement. In the star connection three terminals of the primary coils are united in a common point, and the remaining primary terminals connected to line. The secondary coils are similarly arranged. In the mesh connection all the primary coils are united in series with each other and all the secondary coils are similarly united. The line wires are connected to the three points of union of the primary coils, and the secondary mains connected to the three points of union of the secondary coils. In the three-phase system lamps may be connected between any two wires. The load should be connected so as to require about the same current in each main to give the best results.

**Size of Transmission Line.** In calculating the size of wire formulas giving this in circular mils are usually the most con-

venient. The following formula given in "Electric Lighting," page 52, is one of the simplest and is generally applicable.

$$C.\ M. = \frac{11 \times L \times I}{D}$$

Here $L$ is the length of the circuit in feet, $I$ the current and $D$ the drop.

As an illustration of the use of this formula suppose we wish to transmit 125 amperes a distance of 24,000 feet allowing a drop of 5 per cent. The generator voltage is to be 4,200 volts.

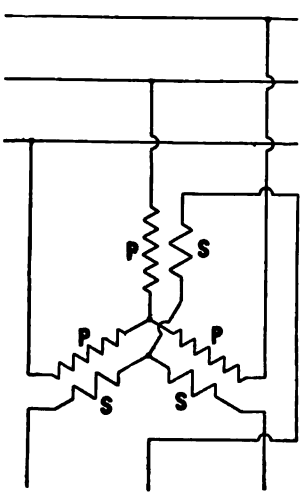



Fig. 13.

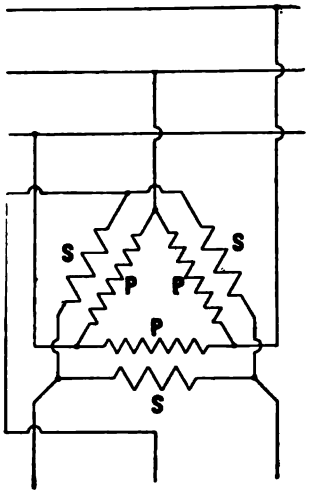



Fig. 14.

The length of the circuit is twice the distance, hence $L = 2 \times 24{,}000 = 48{,}000$. Five per cent. of the generator voltage is 210, so that $D = 210$, and the current is given as 125 amperes. Substituting these values,

$$C.\ M. = \frac{11 \times 48{,}000 \times 125}{210}$$

$$= 314{,}000.\ \text{(approx.)}$$

This is about equal to a No. 0000 and No. 0 wire combined and they would answer for all practical purposes.

No general rule can be given for determining the proper size of wire for every case, since this depends among other considera-

tions upon the quality of service required, amount of power available, nature of service, etc.

Where both power and light are supplied the line loss may in some installations be but five per cent. and in others as much as fifteen per cent. In such a distribution the loss is compensated for by over-compounding the generators, and the voltage at the receiving stations is maintained fairly uniform, if the station is centrally located.

Where motors alone are supplied a considerable variation in voltage may occur at their terminals and still operate in a satisfactory manner. Special care in regard to keeping the voltage uniform is therefore not necessary.

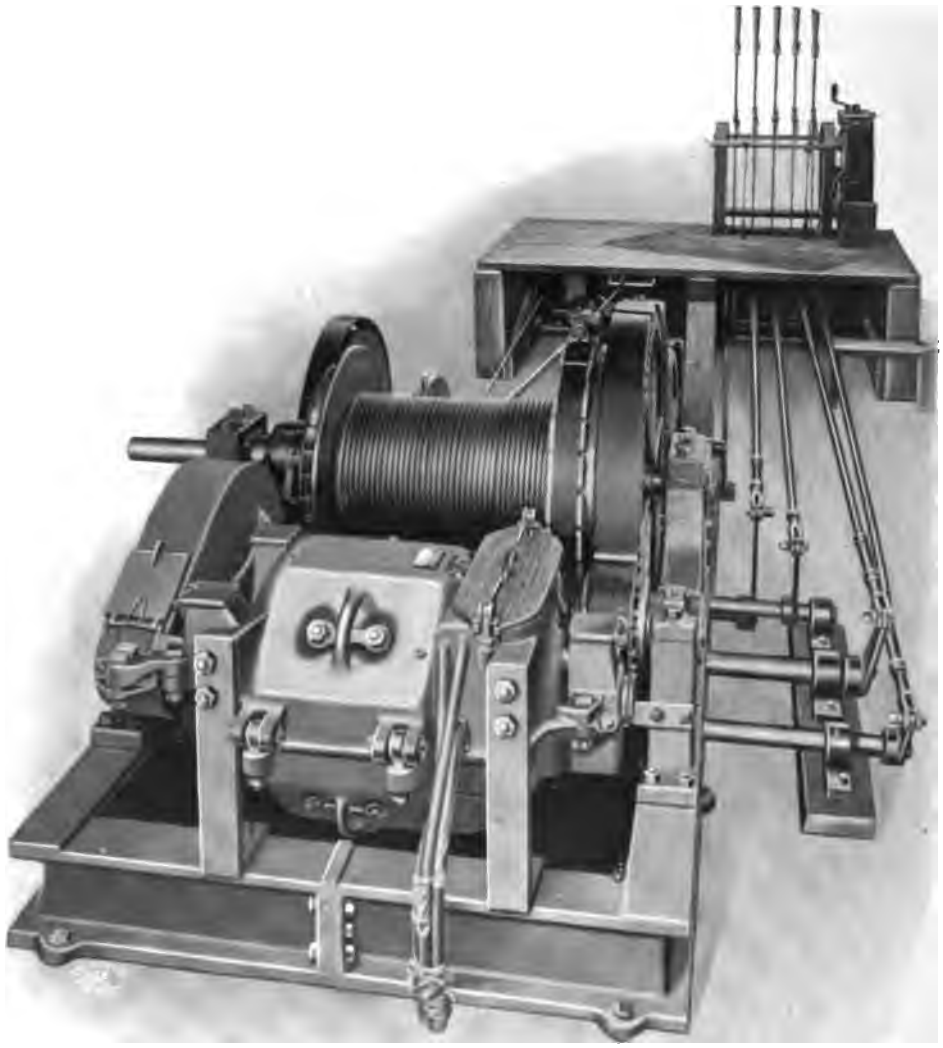
In case there is an *ample* source of water power and motors only are to be used, the size of the mains and consequently their cost can be made small. The main limitation to the size of the mains in such a case is the increase in capacity of the generators. It is evident that the mains could be so small that the loss alone would require the use of larger dynamos than in the case of a moderate loss. If the extra cost of the machines more than balanced the saving in wire, it would, of course, be advisable to use larger mains. The cost of operation would be the same in either case.

Where the cost of power is a definite amount per horse-power, the mains are usually designed for a small line loss, as the extra first cost of the mains is more than compensated for by the reduced loss.

In case a source of power is available, which is limited in amount, and a definite amount of power must be delivered, the line loss must be within the difference. The case might arise in which this difference is small, and the cost of the mains become so high that it would be cheaper to use a moderate size of mains and to install an auxiliary steam plant.

The above cases will indicate how widely the conditions may vary and that each case may have its own peculiarity and must be considered with the special conditions in view.

**Line Inductance.** The inductance which takes place in a coil of wire when the strength of current is varied, also takes place, although to a less extent, in conducting mains. Mains



**LEDGERWOOD HOIST OPERATED BY ELECTRIC MOTOR AND CONTROLLER**
General Electric Company

carrying alternating currents are consequently subject to inductance. As the effect of inductance is to oppose or choke down the impressed E. M. F., the voltage in such a circuit will be reduced at the receiving stations more than the decrease due to ohmic resistance alone. That is, if an alternating circuit is designed for a certain drop due to its ohmic resistance, the drop will be found to be greater after the installation is made. This additional drop, however, involves no loss of power and may be easily compensated for by raising the voltage of the generator slightly.

The ratio of the *combined* ohmic resistance and that due to inductance, to the ohmic resistance alone, is called the *impedance factor.* This factor depends upon the size of wire, frequency and distance between wires. With wires 18 inches apart and a frequency of 60, the impedance factor varies from 1.05 for a No. 6 wire to 2.3 for a No. 0000 wire.

**Distribution.** In hardly any part of a power transmission plant is there so much range of selection and upon which so much depends, as the method of effecting the distribution. The location of the generating plant with reference to the load and the manner in which the load is distributed may depend upon an endless number of conditions.

One of the most common cases is where the power is generated a few miles from a town to which light and power are to be supplied. In this case the solution is comparatively simple. The mains from the power house are led to a point, located as near as can be ascertained at the centre of gravity of the distributing system, and the generators are regulated to keep the potential constant at this point. This is important as the lights to be supplied require a very constant voltage to give good service.

From this central point sub-mains are run to local points throughout the town. At these points reducing transformers are installed, whence the secondary mains lead to the lamps or motors to be operated. The drop in voltage from the central distributing point to each transformer should be equal, or nearly so. It is often desirable to interconnect the secondary mains so that the different transformers may assist each other in case they are unevenly loaded, and thus assist in reducing the fluctuation in

voltage at the lamps. This change in voltage may be kept within 2% of the normal without much difficulty. If the voltage varies as much as 5% above and below the normal, the regulation is considered bad, and the lights give poor service.

An important point in connection with the above method of distribution is the number of transformers used. It was formerly the custom to install a separate transformer for each consumer of light or power. This resulted in the use of numerous small transformers, and the capacity of each transformer was necessarily equal to the maximum load which might occur.

Such an arrangement is objectionable for several reasons. In the first place, the maximum load is very seldom placed upon the transformer, which is ordinarily worked at a small part of its capacity. The transformer being thus worked at a low load, its efficiency is low, as much of the loss is constant whatever the load may be. By replacing these by fewer large transformers, connected to a moderate amount of secondary wiring to the consumers, the efficiency is greatly increased. This is due not only to the efficiency of large transformers being higher than small ones, but also that the aggregate capacity of the large transformers may be less than that of the smaller ones. When several consumers are supplied from a single transformer, the chance that they will all use their full amount of power at the same time is slight. The single transformer can therefore replace several smaller ones of a greater aggregate capacity. The former would consequently be worked nearer its full load in everyday use, and its efficiency would be higher for that reason. Since the loss becomes less the capacity of the generating apparatus may be less, which would be an important item for a large system. There is the further advantage that the cost of the fewer large transformers would be less per kilowatt capacity than the smaller ones.

Additional secondary mains become necessary when large transformers are used but this is more than offset by the advantages. Of course, where the load for a single transformer cannot be grouped within say a few hundred feet, it would be better to install a transformer for each consumer. It is often desirable to install separate transformers for large motors.

The greatest difficulty in planning a system of distribution

arises where power is supplied to several widely distributed towns from a single point, and it is desired to maintain the voltage at the different points nearly constant.

Suppose the station is centrally placed, but the centers to be supplied are at varying distances therefrom. The question arises as to how the mains to the different points may be arranged so that the voltage at each receiving point may be uniform. This may be partly overcome by grouping those loads in which the line loss and conditions are about the same, and for which the same voltage at the generator will answer equally well. The generator may be overcompounded and regulated for these points. The voltage for the other distributed points may be controlled by hand regulators or they may be supplied by separate dynamos. If motors only are supplied, then the variation in voltage need not be especially considered or regulated, and all the mains may be fed from a single dynamo.

If the generating station is at a considerable distance from the points to be supplied (say ten miles) and the receiving points are a few miles from each other, then raising and reducing transformers would be used. A reducing substation would be located at or near the center of gravity of the receiving points, from which mains would lead to the different points and again reduced. In such a case the regulation of voltage on the different lines would be accomplished by regulators located at the substation. If the load at any one of the points were especially heavy, mains may be run directly to the same from the generating station.

No attempt could be made to cover all cases which may arise and the best method to be followed for each, but the above are typical cases.

**Illustrative Installations.** The two following examples are typical American plants for long-distance power transmission. Both are located where the cost of fuel is very high, and power therefore costly when produced from steam.

The plant at Folsom, Cal., is a good example of a plant operating with a heavy flow of water under a moderate head. The wheels are 30-inch double horizontal McCormick turbines, giving 1,250 H. P. per pair at 300 revolutions per minute, under the normal head of 55 feet. Each carries on its shaft a fly-wheel

weighing 15,000 pounds. There are four such units, each consisting of turbines, fly-wheel, governor, coupling and generator. Two smaller wheels drive the two exciters.

The wheel-pit is permanently separated from the dynamo room by a masonry wall, through which the driving shafts project. The water is delivered to the wheels through tubular steel penstocks eight feet in diameter. The gates are controlled by hydraulic cylinders, as are the head gates at the dam.

The four direct-coupled generators are of 750 K. W. each, at 800 volts and 60 cycles. They are designed to run in parallel, although there is a complete circuit for each machine available if wanted. The generators are placed in the lower story of the power house. On the second floor there are twelve General Electric air-blast transformers, which raise the dynamo voltage to 11,000 volts. From these the current passes to the high-tension switchboard and then to the line.

The line is composed of four complete three-phase circuits of No. 0 wire. There are two independent pole lines running a few rods apart. The lines generally follow the roads, and are placed on opposite sides of the roadway. They terminate in a handsome brick substation in the city of Sacramento.

The distribution system is of a mixed character, to supply the different classes of service. The substation dynamo room contains three 300 H. P. three-phase synchronous motors, driving railway generators and arc-lighting machines. These motors take current at 500 volts from reducing transformers. The main distributing circuit is a three-phase four-wire network, giving 125 volts between active wires and neutral.

This plant began operations in 1895. It has been worked continuously, and was successful from the start.

Another excellent example of present practice in long-distance power transmission is afforded by the plant at Fresno, Cal. The power is furnished by the San Joaquin River, 35 miles from the city, at a point where the available head of water is 1,410 feet. The river is capable of supplying over 6,000 horse-power, though at present only a part of this is utilized.

A pipe line 4,100 feet long takes the water from a reservoir formed in the river bed to the power house. The upper end of

the pipe is of riveted steel, 24 inches in diameter. The remainder is of lap-welded steel pipe, of gradually diminishing diameter and increasing thickness toward the lower end, where it is 18 inches in diameter, of $\frac{5}{8}$ inch mild steel.

The pressure corresponding to a head of 1,410 feet is 613 pounds per square inch, and to deal with this requires unusual precautions. There are three main wheels of the Pelton (impulse) type, designed to give 500 horse-power each, at 600 revolutions per minute. Each wheel carries on its shaft a steel fly-wheel weighing three tons, and is coupled directly to a 350-kilowatt General Electric three-phase generator, giving 700 volts at a frequency of 60 cycles per second. The heavy fly-wheels are very effective in keeping the motion of the generators uniform. There are two exciters, each driven by its own wheel of 20 horse-power. All the wheels are independently governed.

Near the generators is a bank of six transformers, 125 kilowatts each in capacity, which raise the generator voltage to 11,200 volts. The current passes from these to the transmission lines, which consist of two three-phase circuits, workable either separately or together. The wire is of No. 00 bare copper, and is carried on special porcelain insulators, tested to 27,000 volts. The poles are 35 feet high, and carry also a telephone line.

The lines are brought to a brick substation in the city of Fresno. Here the reducing transformers and auxiliary apparatus are placed, with arc-lighting dynamos driven by induction motors.

The system of distribution is adapted to the conditions of the service. In the center of the city a three-phase four-wire network is used, supplied from three 125-kilowatt transformers, and working at 115 volts between the active wires and the neutral. For more distant residence sections, three 75-kilowatt transformers supply current at 1,000 volts for use with secondary transformers. For reaching neighboring towns, three 40-kilowatt transformers supply another transmission system at 3,000 volts.

## SECTION 6.

# STORAGE BATTERIES.

Storage or secondary batteries, also called accumulators, consist of cells in which a chemical change is brought about by passing an electric current through them, thereby rendering them capable of giving back electrical energy by discharging them until they return to their original chemical condition.

Ordinarily, a storage battery consists, essentially, of two sets of plates suspended in a chemical solution. The plates are of metal or metallic oxide, and the solution is incapable of acting upon them until an electric current is passed from one plate to the other. This current decomposes the electrolyte; one of its constituent elements or radicals goes to one plate, and the remaining constituent to the other, so that when the passage of the current ceases there are two chemical elements or radicals with a tendency to unite, and upon combination the energy evolved appears as an electric current, which flows in the opposite direction to the charging current. This flow of current continues until the cell is restored to its original condition; when this occurs the cell is said to be discharged.

**A Primary Cell** is one in which electrical energy is produced by the chemical action of one or two solutions on the plates of the cell. When the solutions or plates are exhausted, they are *not* restored to their original condition by the passage of an electrical current.

This reversibility or regeneration is the fundamental difference between storage and primary cells.

**An Electrolyte** is a chemical compound, capable of acting as an electrical conductor, and while so acting, undergoes chemical decomposition. This phenomenon is called electrolysis.

For example, when hydrochloric acid is decomposed by electrical energy, it is decomposed into the elementary gases hydrogen (H) and chlorine (Cl). The chemical formula for this action is,

$$2HCl + \text{Electrical energy} = Cl_2 + H_2.$$

When sulphuric acid is electrolyzed, it is at first split up into hydrogen (H) and the radical sulphion ($SO_4$); the latter combines with the water of solution present and reforms sulphuric acid ($H_2SO_4$) and oxygen is liberated. The chemical equations for the above primary and secondary reactions are:

$$2H_2O + 2H_2SO_4 + \text{Electrical energy} = 2H_2 + 2SO_4 + 2H_2O$$
$$2H_2 + 2SO_4 + 2H_2O = 2H_2 + 2H_2SO_4 + O_2$$

The modern theory of electrolysis assumes that in an electrolytic solution there are always free ions which wander around promiscuously, until the application of an electric current directs their wanderings into certain definite directions.

Any salt dissolved in water is ionized, that is, some portion is separated into the two component parts of the salt.

When certain metals such as Potassium or Sodium are free in an ionized solution they are said to be in an allotropic state, and when the current is passed through the solution, the metal is freed from its allotropic state, and will in such cases, form hydrates, (KOH)—(NaOH). The theory also states that the conductivity of electrolytes is due to the presence of these allotropic ions.

In 1802, soon after the invention of the primary cell by Volta, Cautherot demonstrated the fact that platinum wires, after being used to electrolize saline solutions, were able to produce secondary currents. Volta, Ritter, Davy and others noted similar effects, the phenomenon being what is commonly called polarization. In 1859 Planté undertook a series of experiments with the object of studying and magnifying this effect and finally developed the Planté type of storage battery; nearly all successful types of storage batteries of the present day are based upon the Planté cell.

**Types of Storage Batteries:**

Planté,
Faure,
Combination of Planté and Faure,
Non-lead.

## PLANTÉ BATTERY.

This cell was originally made by placing two plates of metallic lead in a vessel containing dilute sulphuric acid. These plates were connected to an electric generator, and a current sent through the cell, which decomposed the electrolyte and oxidized the positive plate. The cell was then discharged; but the energy obtained was very small, since the action was confined to the immediate surface of the plates. By repeated charging and discharging first in one direction and then in the other, the oxidation penetrated deeper and deeper into both plates, thus increasing the storage capacity of the cell.

The chief difficulty with the Planté battery was the great length of time required for "forming" the plates, which as just explained consists in converting the surface of the plates into active materials, by repeated chargings and dischargings. This takes about three days and is expensive, as it requires a large consumption of electrical energy. Later on in his investigations, Planté hastened this forming process by pickling the plates in dilute nitric acid, then washing them in a 10 per cent sulphuric acid solution, after which they were electrically formed. An inherent difficulty with the Planté system is that plates well adapted to the forming process are difficult to make.

In 1881 Faure devised the method of pasting the lead oxide or active material directly upon the plates. This largely avoids the tedious forming process; but the plates thus produced are not as durable as the Planté elements, being more likely to disintegrate and buckle, because the paste is not an integral part of the plate and there is considerable difference in the coefficients of expansion of lead and the oxide.

Innumerable forms of storage batteries have been invented, and many of them have been exploited, in which copper, zinc, iron and other metals or elements instead of lead were used; but almost all of those now being manufactured and used commercially are of some lead type. Such being the case, it is safe to assume or infer, that this lead combination possesses distinctive features not present in the other combinations; and upon investigation, it is apparent that these features are that the electrodes, the active materials and the compounds formed from them are,

under every normal condition of use, insoluble in the electrolyte employed.

In every other form of battery now on the market, one or even both of the electrodes or materials formed on them are soluble in the electrolyte, and this solubility is fatal to the storage power and life of the cell.

**General Principles of the Storage Battery.** Any primary battery will act as a storage battery provided its chemical action is reversible. The ordinary gravity cell, for example, may be regenerated by sending a current through it in the direction opposite to that produced by it. The zinc sulphate and the metallic copper are thus reconverted into metallic zinc and sulphate of copper respectively, the chemical action being

$$ZnSO_4 + Cu + \text{Electricity} = Zn + CuSO_4,$$

which is exactly the reverse of the action in the primary cell. There are, however, practical difficulties in the continued recharging of a spent gravity cell, due to the ultimate mixture of the sulphate solutions and the soluble salt reaching the negative electrode where it is deposited and sets up destructive local action; this action was referred to in the preceding paragraph.

In some forms of primary cells, the chemical action liberates a gas that escapes, so that the action is obviously irreversible.

**Chemical Action in Lead Storage Batteries.** The exact nature of the chemical changes which occur in lead batteries, is not yet fully established. Planté believed the charging action to consist in the formation of peroxide of lead ($PbO_2$) on the positive plate, and metallic lead on the negative, which were converted into lead oxide (PbO) on both plates by the discharge. Some authorities still maintain this to be the chief reaction; but it has been shown by Gladston and Tribe, and corroborated by subsequent investigations, that the formation of lead sulphate plays an important part.

The probable reaction may be represented as follows:

| | Positive Plate. | | Electrolyte. | | Negative Plate. |
|---|---|---|---|---|---|
| Charged Condition | $PbO_2$ | + | $2H_2SO_4$ | + | Pb |
| Discharged | $PbSO_4$ | + | $H_2O$ | + | $PbSO_4$ |
| Charging Current | | | ⋙⟶ | | |
| Discharging Current | | | ⟵⋘ | | |

According to the above equations, the active material on both plates is converted into lead sulphate when the battery is discharged. The reasons for believing this to occur are: *first*, chemical analysis shows that lead sulphate exists in the discharged plate, *second*, the density of the electrolyte decreases during the discharge of the cell, corresponding to the consumption of sulphuric acid and the formation of water as shown in the above reactions, *third*, on the thermo-chemical grounds, the combination of lead and oxygen as lead oxide (PbO) does not evolve sufficient heat to account for the E. M. F. or voltage produced.

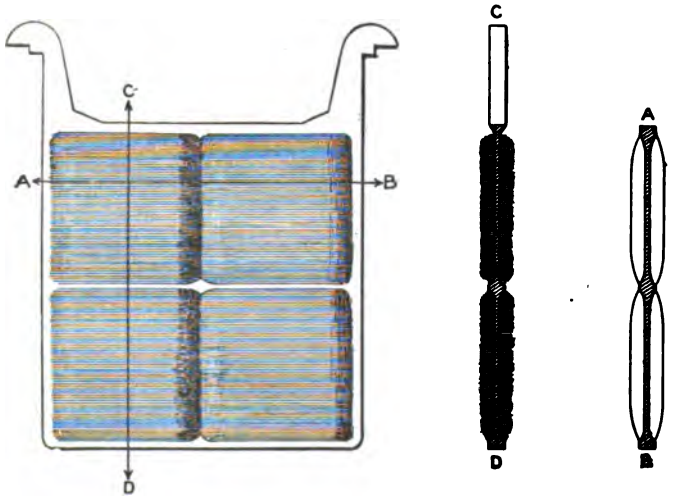



**Fig. 1. Cut of the Gould Storage Battery Plate.**

**Storage Batteries of the Planté Type.** We have seen that the serious objection to the Planté battery was the great length of time necessary to form the plates, and how Planté treated them with nitric acid to hasten this action. Other methods are used to obtain a quickened formation, and are tabulated as follows:

1. *Mechanical Action:* Laminated plates are made up of lead ribbons. The surface of the plate is grooved with some forming tool. Built up of lead wires, etc.
2. *Chemical:* Treating the plates in some pickling bath, to produce initial oxidation.
3. *Electrolytic:* Forming a plate of some compound of lead or an alloy, and either reducing the compound or eating the foreign matter away, leaving a porous lead plate.

**The Gould Storage Battery.** This battery is made by the Gould Electric Storage Battery Company of N. Y., and the plates are produced by a combination of the first and third methods. The plates or blanks are placed in steel frames and given a reciprocating motion between two revolving shafts which carry grooving discs, giving the plates a surface as shown in Fig. 1. No lead is removed by this process but the surface is ploughed up. It is then subjected to electro-chemical treatment to form the active material. The completed cells range in size from a cell of three plates 3 inches by 3 inches, to one of one hundred and five plates each 15.5 inches by 31 inches, and in capacity in ampere-hours from five to seventeen thousand.

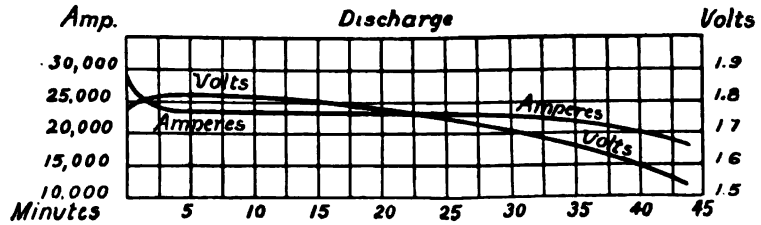



Fig. 2. Discharge Curve of a Gould Type "T" Battery.

The curves shown in Fig. 2 are reproductions of curves obtained from tests of one of their type — T batteries, plates each 15.5 inches by 31 inches, and 101 in number, made at the Pan American Exposition. The weight of this battery complete is about seven thousand and fifty pounds.

**The Crompton Howell Battery.** A standard form successfully used in England, is of the Planté type, the plates being composed of a porous crystalline lead, made according to method 3 (see page 5) and afterwards "formed" by repeated charges and discharges. The regular dimensions of the plates are 9 inches by 9 inches by $\frac{1}{4}$ inches, and the cells are made up by increasing the number of plates. A cell of this type with sixty-one plates can maintain a discharge of 1000 amperes for thirty minutes without a serious fall in potential.

### FAURE TYPES OF STORAGE BATTERY.

As has been stated, the difficulty with the Faure type is the natural tendency to disintegrate or buckle. Various methods to

increase the permanency of the adhesion of the active material have been suggested of which the most important are as follows :

1. Plates are grooved, roughened, or "pocketed."

2. Plates are entirely perforated, the holes being circular, or rectangular, and varying in cross section; some have a uniform section through the grid A, Fig. 3, others are contracted at the

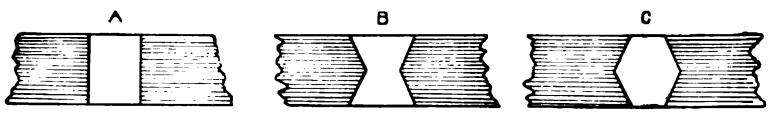



**Fig. 3. Different Cross Sections of Faure Plate Perforations.**

center B and again they may be expanded at the center of the grid C.

3. The active materials may be enclosed in either a conducting or non-conducting cage.

4. The plates may be made up entirely of active material.

Faure cells usually have a greater weight efficiency than Planté types because the proportion of active material may be made greater.

**The E. P. S. Battery** is one of the most important of the

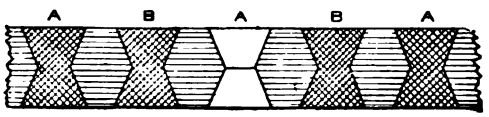



**Fig. 4. Section of E. P. S. Battery Plate.**

Faure type, its name being the initials of the Electric Power Storage Company by which it is manufactured in England. It is sometimes called the Faure-Sellon-Volckmar cell, being made under the combined patents of these and several other inventors.

The plates consist of lead grids cast in an iron mold, and have the cross-section shown in Fig. 4. The latter types have a thin perforated strip of metal (lead) running across each opening midway between the edges. The holes A in the grid are completely filled with a paste of red lead or minium ($Pb_3O_5$) and dilute sulphuric acid for the positive, while the paste for the negative

consists of minium, or litharge (PbO) and dilute sulphuric acid, or a magnesium sulphate solution. These pastes are pressed into the grids and dried.

The plates are hardened in dilute sulphuric acid, after which they are ready for forming. A strong current of 48 hours' duration is required for the positive plate and twenty-four hours is required for the formation of the negative plate. To prevent short circuiting after the cells are set up, the plates have glass rod separators placed between them.

The E. P. S. batteries are made in many different sizes and types, of which the L type is a good example, being used extensively in isolated plants. Data of this type are as follows:

E. P. S. ACCUMULATOR, L. TYPE.

| No. of Plates. | Maximum Normal Charge or Discharge Rate. | Capacity Ampere Hours. | Approximate External Dimensions. | | | Weight Complete with Acid Wooden Cell. |
|---|---|---|---|---|---|---|
| | | | Length. | Width. | Height. | |
| 7 | 13 amperes | 130 | 5½ in. | 13½ in. for wooden and 12 for glass cell. | 18 in. for wooden and 13½ for glass cell. | 74 lbs. |
| 11 | 22 " | 220 | 8 | | | 107 " |
| 15 | 30 " | 330 | 9½ | | | 143 " |
| 23 | 46 " | 500 | 14½ | | | 228 " |
| 31 | 60 " | 660 | 19 | | | 286 " |

One of the smaller types of the E. P. S. battery is used extensively in England in electric vehicle work.

**The Exide Battery** is manufactured by the Electric Storage Battery Co., of Philadelphia, chiefly for electric vehicle duty. The plates are of the Faure type, and consist of lead-antimony grids (about 5 per cent antimony) pasted with oxides of lead.

The grid for the positive plate is of the cage type, consisting of thin vertical ribs, the edges of which are flush with the faces of the plate, and connected by small bars of a triangular cross section; the bars on one face are staggered with respect to those on the other side. This finished form is then pasted up with red lead ($Pb_3O_5$) and formed in the usual way; the thickness of the

finished plate is about $\frac{7}{32}$ inch. From this description it is evident that the plate is made up in accordance with method 3 described on page 7, the enclosing cage being of conducting material. The active material is in the form of rectangular pencils extending from the top of the plate to the bottom. The thin flat ribs are on two sides of these pencils and the triangular cross pieces are imbedded in the other two sides which constitute the faces of the plates. The exide cell is shown in Fig. 5.

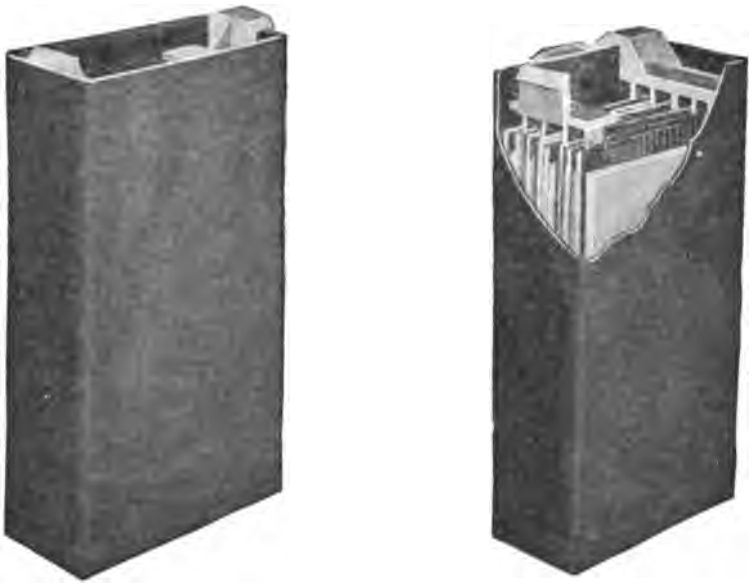


**Fig. 5. Cut of an Exide Battery.**

The negative plate consists of a thin antimony lead sheet, with a comparatively heavy frame of cast lead. The body of the sheet is perforated at regular points and very close together. These perforations are not actual punchings (being made by a tool which does not remove the material) but are simply holes torn in the plate leaving the material around the hole in ragged projections which curve back towards the sheet, and form as it were a series of hooks. These projections are formed on both sides of the plates.

The grid is then pasted with litharge (PbO) on both faces; it is held to the plate by the "hooks" as well as being "riveted"

by passing through the holes which the projections surround. The thickness of this finished plate is about $\frac{3}{16}$".

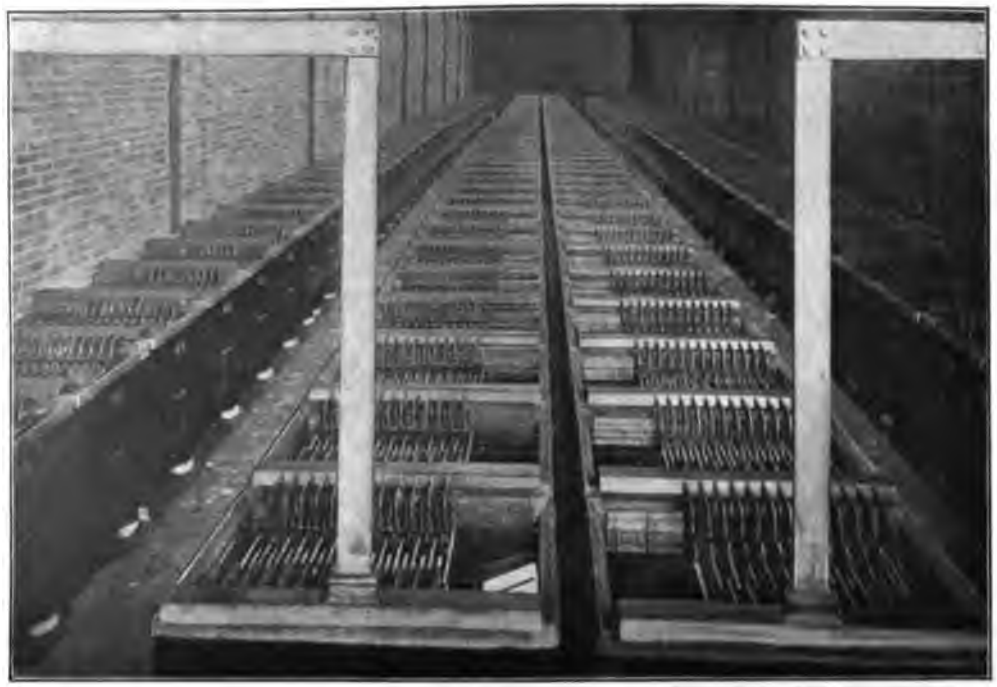
When assembled, the plates are placed in rubber jars of

DATA SHEET EXIDE CELLS.

| TYPE. | —M. V.— | | | | | | | —P. V.— | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Plates. | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 5 | 7 | 9 | 11 | |
| Discharge in Amps for 4 Hours. | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 12 | 18 | 24 | 30 | |
| Size of Plates. | | | | | | | | | | | | |
| Length (inches). | 5½ | same | same | same | same | same | same | 4½ | same | same | same | |
| Height (inches). | 8¾ | same | same | same | same | same | same | 8¾ | same | same | same | |
| Outside Measures of Rubber Jars. | | | | | | | | | | | | |
| Width (inches). | 2⅞ | 3¾ | 4¾ | 4½ | 5⅛ | 6¼ | 7⅛ | 1⅛ | 2⅛ | 3¼ | 4¼ | |
| Length (inches). | 6⅛ | same | same | same | same | 6 | 6 | 5⅛ | same | same | same | |
| Height (inches). | 11½ | same | same | same | same | 11 | 11 | 11½ | same | same | same | |
| Weight in Pounds. | | | | | | | | | | | | |
| Elements. | 15½ | 20½ | 25½ | 30½ | 35 | 40 | 44½ | 9½ | 13½ | 17½ | 21½ | |
| Electrolyte. | 2½ | 3½ | 4½ | 6½ | 7 | 8 | 8½ | 1½ | 2½ | 3 | 4½ | |
| Complete Cell. | 19½ | 25½ | 31½ | 33½ | 44½ | 50 | 56 | 11½ | 17½ | 21½ | 27½ | |

dimensions as above, and separated from each other by wooden partitions. In addition a perforated rubber sheet is placed against the faces of the positive plates.

The brougham or hansom battery of this type of cell consists of 44 cells of TV–9 size, having four positive and five negative plates. The weight of this outfit complete with tray is about



THE PITTSBURG RAILWAY COMPANY'S BATTERY PLANT, INSTALLED BY THE ELECTRIC STORAGE BATTERY COMPANY.

1659 pounds, the capacity 156 ampere hours (4 hour, 39 ampere rate), the average voltage during discharge about 1.98 volts per cell or 87 volts for 44 in series, the total watt-hour output being therefore 13,572, or 8.19 per pound.

### COMBINATIONS OF PLANTÉ AND FAURE TYPES.

**The Chloride Battery,** manufactured by the Electric Storage Battery Company of Philadelphia and allied companies in England, France and Germany, is a compromise between the Planté and Faure types, the positive being of the Planté type, and the negative of practically the Faure type.

The principal features in the manufacture of this battery are as follows: The first step is the production of finely divided lead, which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which upon cooling falls as a powder. This powder is dissolved in nitric acid ($HNO_3$) and precipitated as lead chloride ($PbCl^2$) on the addition of hydrochloric acid (HCl). This chloride washed and dried forms the basis of the material which afterwards becomes active in the negative plate B, Fig. 6. The lead chloride is mixed with zinc chloride, and melted in crucibles, then cast into small pastiles or tablets about $\frac{3}{4}$ inch square and of the thickness of the negative plate, which according to the size of the battery varies from $\frac{1}{4}$ inch to $\frac{5}{16}$ inch. These tablets are then put in molds and held in place by pins, so that they clear each other by .2 inch and are at the same distance from the edges of the mold. Molten lead is then forced into the mold under about seventy-five pounds pressure, completely filling the space between the tablets. The result is a solid lead grid holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. This assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

This company has recently designed a new form of negative, which promises to replace the chloride type just discussed. It consists of a "pocketed" grid, the opening being filled with a litharge paste; this is then covered with perforated lead sheets,

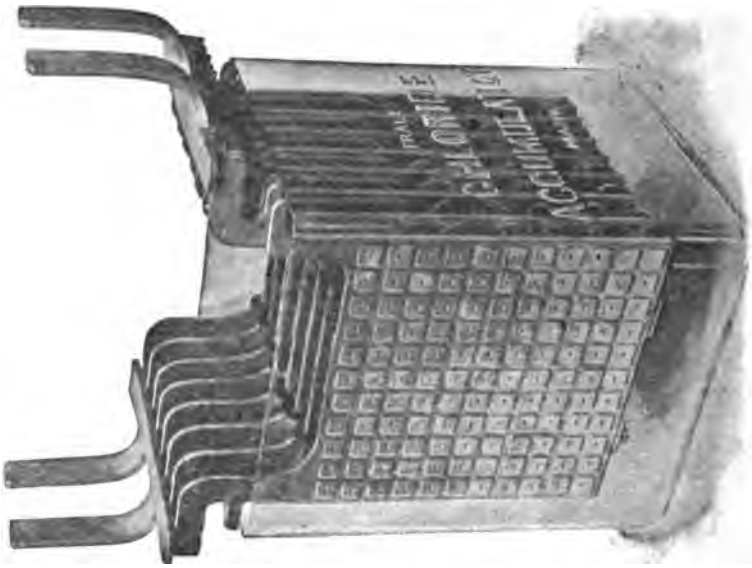


Fig. 6. Right.

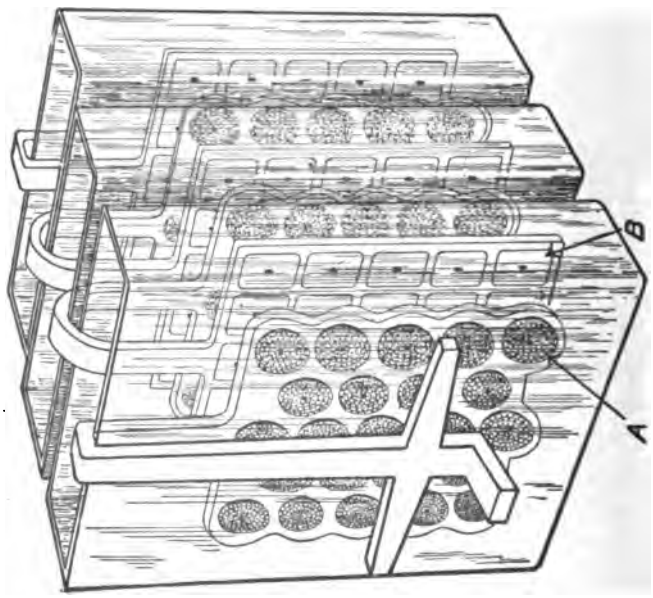



Fig. 6. Left. Fig. 6 The Chloride Cell, Showing Plate Construction.

which are soldered to the grid. The positive plate (B, Fig. 6) is a firm grid, composed of lead alloyed with about 5 per cent of antimony, about $\frac{7}{16}$ of an inch thick, with circular holes $\frac{25}{32}$ of an inch in diameter, staggered so that the nearest points are .2 of an inch apart. Corrugated lead ribbons $\frac{7}{16}$ of an inch wide are then rolled up into close spirals of $\frac{25}{32}$ of an inch in diameter, which are forced into the circular holes of the plate.

By electro-chemical action, these spirals are formed into active material, the process requiring about thirty hours; at the same time the spirals expand so that they tend to fit still more

DATA CHLORIDE BATTERY.

| TYPES. | B. | C. | | BT. | CT. | PT. | D. | | E. | | F. | | G. | | H. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size of Plate in inches | 3x3 | 4½x4 | | 3x4 | 5x5 | 8½x5 | 6x6 | | 7½x7½ | | 11x10½ | | 15½x15½ | | 15½x30¾ | |
| Number of plates | 3 | 3 | 7 | 2 | 2 | 2 | 3 | 13 | 5 | 15 | 9 | 27 | 11 | 75 | 21 | 75 |
| Discharge in Amperes — For 8 hours | ⅜ | 1½ | 3¾ | ¾ | 1½ | 3 | 2½ | 15 | 10 | 35 | 40 | 130 | 100 | 740 | 400 | 1480 |
| Discharge in Amperes — 5 | ⅞ | 1⅞ | 5¼ | 1 | 2 | 4¼ | 3½ | 21 | 14 | 42 | 56 | 182 | 140 | 1036 | 560 | 2072 |
| Discharge in Amperes — 3 | 1½ | 2½ | 7½ | 1½ | 3 | 6 | 5 | 30 | 20 | 70 | 80 | 260 | 200 | 1480 | 800 | 2960 |
| Discharge in Amperes — 1 | | | | | | | | | 40 | 140 | 160 | 520 | 400 | 2960 | 1600 | 5920 |
| Normal Charge Rate | ⅜ | 1½ | 3¾ | ¾ | 1½ | 3 | 2½ | 15 | 10 | 35 | 40 | 130 | 100 | 740 | 400 | 1480 |
| Outside dimensions of glass jars, inches. — Width | 2½ | 3½ | 5¼ | 1¾ | 2¼ | 2¼ | 3½ | 11 | 5½ | 11 | 9 | No glass jars for these large sizes. | | | | |
| Outside dimensions of glass jars, inches. — Length | 4 | 5¼ | 5¼ | 3¾ | 6¼ | 6 | 7¼ | 8¼ | 9½ | 9½ | 12⅜ | | | | | |
| Outside dimensions of glass jars, inches. — Height | 6½ | 7½ | 7½ | 6¾ | 8 | 12 | 9½ | 9½ | 11⅜ | 11⅜ | 15½ | | | | | |
| Outside dimensions for lead lined wooden tanks. — Width | | | | | | | | | | | 11⅜ | 28¾ | 15¾ | 73½ | 26¼ | 73½ |
| Outside dimensions for lead lined wooden tanks. — Length | | | | | | | | | | | 15 | 15 | 19¾ | 21¼ | 21¼ | 21½ |
| Outside dimensions for lead lined wooden tanks. — Height | | | | | | | | | | | 17¾ | 17¾ | 23 | 24¼ | 42⅜ | 48⅞ |
| Wht. of cell complete with acid and glass jar (lbs) | 5½ | 10½ | 20 | 4½ | 9½ | 18 | 20 | 64 | 48¾ | 112 | | | | | | |
| Ditto. Lead lined tanks. | | | | | | | | | | | 217 | 531 | 526 | 3086 | 1817 | 5786 |

closely in the grids. This form of positive is that known as the Manchester Plate.

In setting up the cells, the plates are separated from each other by special cherry wood partitions, the perforations being connected by vertical grooves to facilitate the rising of the gases. Sometimes glass rods are used as separators.

The table gives the data of the various types and sizes of cells. To save space only the smallest and largest sizes of each type are given, but in all cases intermediate sizes are made with

every odd number of plates. The capacities, weights, etc. are of course nearly proportional to the number of plates.

The smaller sizes are provided with either rubber or glass jars, and the larger ones, from F up, with lead-lined tanks.

**The Tudor Cell** is very extensively used in Europe, and to some extent in this country, although it is no longer manufactured here. The American patent rights are controlled by the Electric Storage Battery Company.

The plates consist of rolled, grooved sheets as shown in Fig. 7, A being the hollows or grooves into which the paste is set and B the lead frame. The thickness of the plate between opposite grooves is about .12 inch for the positive, and about .06 inch for the negative. The width of grooves on the positive plate is also about .12 inch, while on the negative it is about .08 inch. The grooves are first coated with a thin layer of peroxide of lead ($PbO_2$) by electrolysis, and then packed with the oxides as required; the plates are then rolled to "fix" the paste. This treatment of the grid with an electrolytic bath before applying the active material, is covered by U. S. patent No. 413,112.

TUDOR CELLS.

| Type. | Available Capacity. | Maximum Current in Amperes. | | Dimensions of Cells in Centimeters. | | | Total Weight. |
|---|---|---|---|---|---|---|---|
| | Amp. Hours. | Charge. | Discharge. | Length. | Width. | Height. | Kgms. |
| I | 26 | 6 | 8 | 12 | 21 | 35 | 10 |
| V | 91 | 21 | 28 | 30 | 21 | 35 | 30 |
| X | 270 | 54 | 72 | 42 | 42 | 55 | 110 |
| XIV | 630 | 126 | 168 | 74 | 42 | 55 | 230 |

In addition to those given above, all of the intermediate sizes are made.

A battery of larger cells is in use in the Head Place Station of the Edison Company of Boston, Mass., a description of which is given in the Electrical Engineer (N. Y.) of Sept. 18, 1895. The plant contains two batteries of 72 cells each. Each cell consists of a lead-lined wooden box, 3 feet 10 inches long, 3 feet 4 inches wide, and 3 feet deep, in which are suspended 18 positive

and 19 negative frames. Each positive frame is composed of 16 plates 7 inches square ; while each negative frame has 4 plates 14 inches square, thus giving an enormous surface in each cell. The plates are secured in their respective frames by lead strips. The frames are held in position about $\frac{1}{2}$ inch apart by vertical glass tubes, and rest upon thick glass plates placed on edge in the bottom of the cell; the frames being thus raised 6 inches above the floor of the cell. It is said that these two batteries combined are capable of supplying 6,600 amperes at 110 volts for $1\frac{1}{4}$ hours, which would usually cover the period of very heavy load. This is an output of 726 kilowatts, or nearly 1,000 horse-power for $1\frac{1}{4}$ hours, being a remarkably high discharge rate.

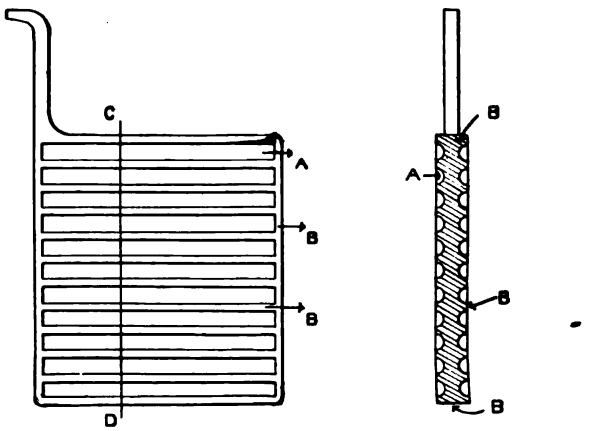



**Fig. 7. The Tudor Battery Plate.**

It is recommended for central-station use, particularly where the rate of discharge is great, as, for example, when the total time of discharge is only $1\frac{1}{2}$ to 4 hours. For this work the negative plates are of the Chloride type, the positives being the heavy Tudor plates described above.

**Lithanode.** Mr. Desmond Fitzgerald has made storage batteries with a positive plate consisting entirely of active materials made up of litharge (PbO) mixed with ammonium sulphate $(NH_4)_2\ SO_4$ which he pressed into the required shapes. This plate is converted into peroxide by chemical treatment. The negative of this cell consists of the ordinary lead plate. While this cell has an exceedingly high weight efficiency it is not of

much commercial importance, though used considerably in laboratory work.

It is the tendency in Europe to make the positive plate of the Planté form and the negative of the Faure or pasted type. The reason for this is that the Planté form is hard to make, and as the activity is small on the negative the pasted plate is good enough.

The practice in lead batteries is to make the negative plate of greater capacity than the positive, as the charging and discharging of a cell in service tends to produce or form more active material on the positive plate, whereas the negative plate is made to decrease, so that allowance for this is made as above stated.

**Storage Batteries Containing Metals other than Lead.** It has already been stated that almost any primary cell will act more or less perfectly as a secondary cell; as, for example, the common gravity battery. A great many have been devised in which the lead in one or both of the plates has been replaced by some other metal. For example, Reynier made the negative plate of zinc instead of lead, this zinc in discharging being converted into zinc sulphate, which dissolved in the electrolyte. The substitution of zinc for lead secures an increase in initial E. M. F. from 2.2 to 2.5 volts, and also allows of a considerable reduction in weight; since for the storage of a given amount of energy the weight of the zinc required is much less than that of the equivalent lead. A difficulty with this type of cell is the formation of "trees" of zinc on the negative plate during the charging process, which are likely to fall off or extend across to the positive plate, thus short-circuiting the cell.

Another difficulty is the difference in density of the solution between the top and bottom of the plates, the tendency being to exhaust the zinc sulphate from the upper portion of the liquid during charging. In order to avoid this trouble the plates have been arranged horizontally, so that the density would be uniform for each plate; but the difficulty then arises that the gases which form to a certain extent in almost all batteries collect between the plates and interfere with the chemical action and the passage of the current.

A similar type of cell has been manufactured by the Union Electric Company of New York, in which the negative plates con-

sist of thin sheet copper covered with an amalgam of zinc, and the positive plates are made up of laminæ of lead held together by leaden rivets and perforated with numerous small holes, these positives being formed by the Planté process.

**Waddell-Entz Accumulator.** The copper-alkali-zinc primary battery of Lalande, Chaperon and Edison being reversible in action, can be used as a storage battery. Waddell and Entz have constructed accumulators on this principle. When discharged, the positive plate consists of porous copper; the electrolyte is decomposed, metallic zinc being deposited on the negative plate, the porous copper of the positive plate is oxidized, and the liquid

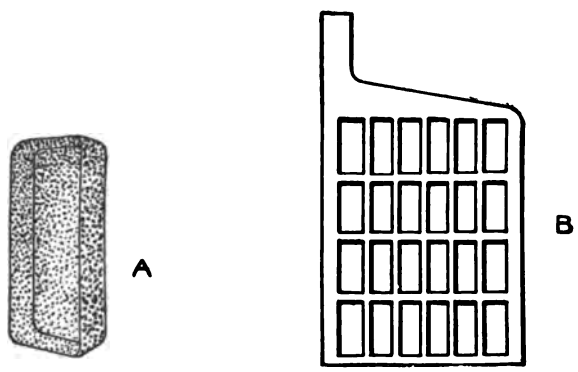



Fig. 8. Construction of Edison Battery Plate.

becomes converted into a solution of caustic potash (potassium hydrate).

This storage battery has been used with considerable success for traction purposes, but its E. M. F. is so low, being only about .7 volt, that it would require 170-180 cells for the ordinary 119 volt electric-lighting circuit, allowing for loss of potential in the battery and conductors. This number is three times as great as is required with the lead battery. This is a serious objection in this or any other low voltage cell.

**The Edison Storage Battery** manufactured by the Edison Storage Battery Company of Newark, N. J., consists of a positive plate of super-oxide of nickel ($NiO_2$) and a negative plate of iron, suspended in about a 20 per cent solution of caustic potash (KOH).

The mechanical construction of both plates (positive and negative) is the same, and the grids are made of nickel-plated steel, shaped as represented at B, Fig. 8. Each opening in the grid is filled with a perforated shallow pocket A or box of nickel-plated steel which contains the active material, and projects out beyond the body of the grid.

The active material is made up in the form of briquettes; one briquette being placed in each pocket. A perforated cover of nickel steel is placed over each pocket. After the plates are fully assembled they are subjected to a pressure of about 100 tons,

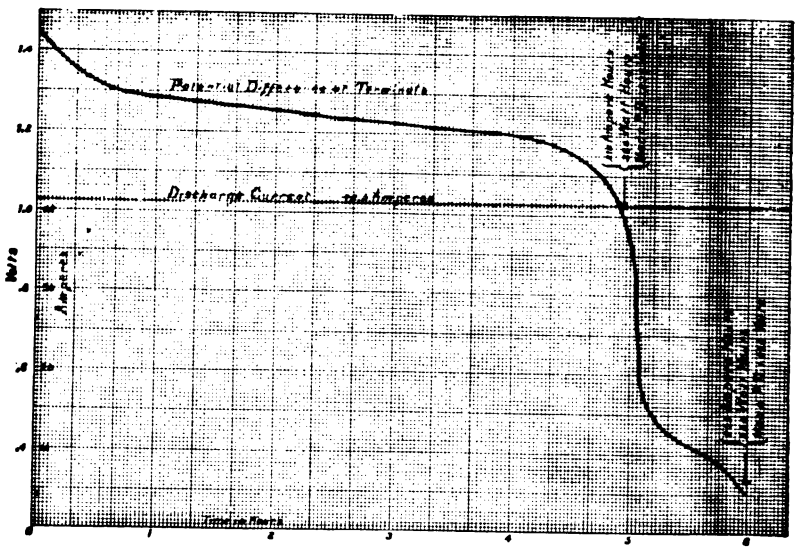


Fig. 9. Curve of Voltage of Edison Cell During Discharge.

which firmly forces all parts into a practically solid mass, making good electrical contact between the pockets and the grid, at the same time turning the edges of the pockets over their respective covers. The active material or briquette consists of a finely divided compound of nickel mixed with about an equal amount of flaked graphite, for the positive plate, and for the negative plate it consists of a finely divided compound of iron, with an equal amount of flaked graphite. This graphite has no chemical connection with the action of the cell but is used simply to increase the conductivity of the briquettes.

The finished plates have a thickness of about $\frac{1}{40}$ inch across the web, and across the pockets of about $\frac{1}{10}$ inch.

The size of the plate varies with the capacity of the cell, having a greater or less number of pockets. The containing jar is also made up of nickel-plated steel sheets.

The initial voltage of discharge after recent charge is 1.5 volts.

The mean voltage of full discharge is 1.1 volts.

This cell has an energy capacity or weight efficiency of 14 watt-hours per pound of complete cell.

Charging and discharging rates are alike, that is to say, the cell may be charged at a normal rate in $3\frac{1}{2}$ hours; or it may be charged at a high rate in one hour, without apparent detriment beyond lowering the efficiency.

The current enters the cell at the positive plate and oxidizes the nickel compound to the peroxide state, and reduces the iron compound to spongy iron.

The electrolyte in this cell simply acts as a path for the passage of the oxidizing and reducing irons, and its own chemical composition does not change.

The cell is not appreciably influenced by changes in temperature. It is claimed that it may be fully discharged to the zero point of E. M. F. without injury, can be charged in reverse direction, then recharged to its original condition and suffer no loss in its storage capacity. The curve given in Fig. 9 shows a six hour discharge of an experimental cell, at a constant current of 42.5 amperes.

## MANAGEMENT OF STORAGE BATTERIES.

In describing the handling of storage batteries, the various types of lead cells will be considered, as they constitute a very large majority of cells in commercial use.

**The Battery Room.** In the installation of a battery, the first point to be considered is its location. The room for this purpose should be dry, well ventilated and of a moderate temperature, otherwise the evaporation of the electrolyte will be excessive. The floor, walls and ceiling must be of some acid proof material, brick or tile being preferable, and the floor so made as to drain readily; an outlet being provided for the drainage system. If the room

should be an old one, and have a wooden floor, the floor should be coated with asphaltum paint, and lead trays placed below the batteries; any wood work or iron work in the room should be likewise treated.

The room should be sealed from the rest of the building, and located near the generating machinery and distribution switchboard, so that the copper cables may be low in cost. The windows in the battery room should be either of ground or painted glass, so that no direct rays of the sun may strike the cells, as the heat may crack the cells (glass) or increase the activity of the acid, which is not desirable.

In case the battery installation is in a cold climate, some device for keeping the electrolyte at a moderate temperature must be used. A simple plan is to suspend an incandescent lamp in the

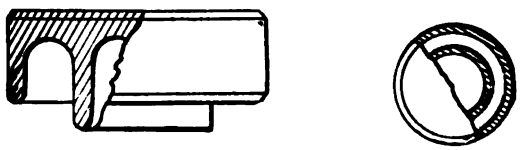


Fig. 10. Glass Insulator for Battery Support.

cell and have it connected to some automatic device which will put it out when the electrolyte is at the desired temperature or light it when the electrolyte is too cold.

**Setting up the Cells.** The battery is usually placed on the floor, or upon strong wooden shelves; Fig. 11 shows a form adapted to cells of medium size. Iron stands are sometimes used for large and heavy cells, but they must be protected from acid fumes and drip by several coats of an acid-proof paint. Wooden stands should be varnished, painted or soaked in paraffin for the same reason. It is important to have every cell accessible for inspection, cleaning and removal, it being desirable to reach both sides of the cell. There should also be sufficient head room between shelves so that the elements may be lifted out.

It is highly important that the cells be thoroughly insulated from each other, to avoid leakage of current. This is accomplished by standing each cell on four insulators of porcelain or glass of the design shown in Fig. 10. Porcelain is preferable to

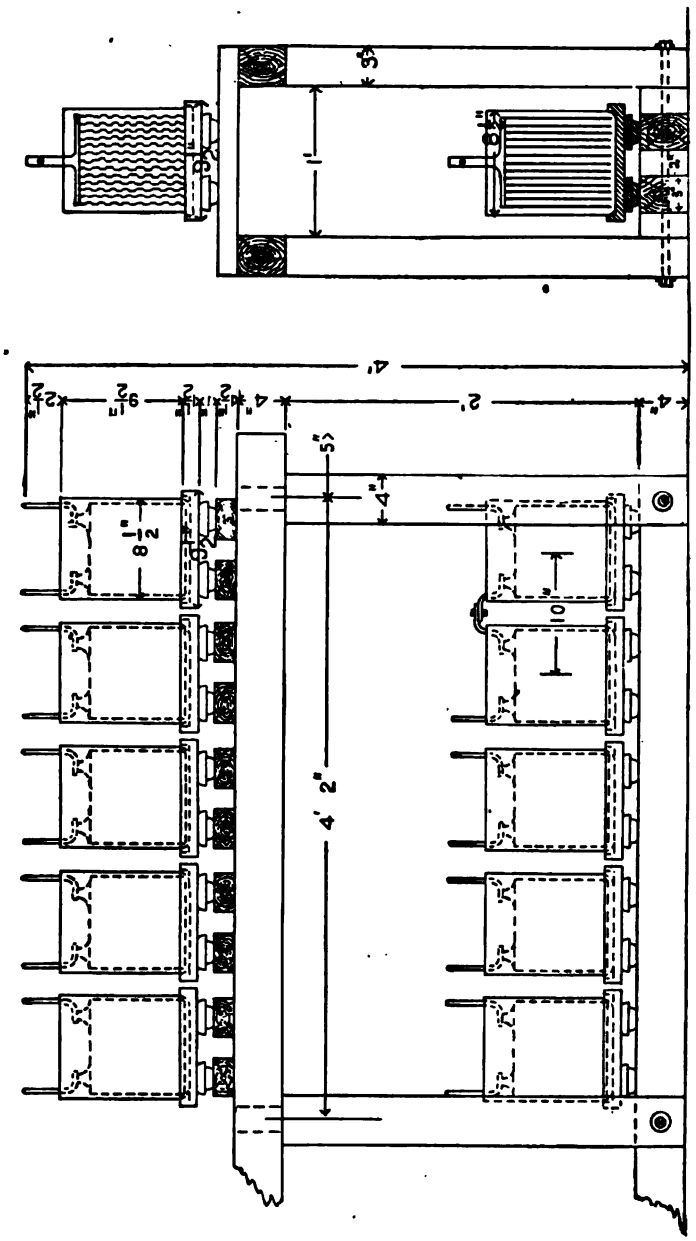



Fig. 11. Shelf Construction for Battery Support.

glass as the latter is sometimes pitted by the action of acid fumes.

Lead-lined tanks are usually set as follows: The floor is covered with a layer of glazed tile or brick; on this are placed two wooden stringers about 3 inches x 4 inches carefully painted with P & B or some acid-proof paint. On these are set four insulators held in place by wooden pegs which are kept in position by pouring melted sulphur around them. On top of these are placed the battery tray and battery as indicated in Fig. 11.

Oil insulators were at first used, but as oil collects and holds dust they are no longer used, as this dust is likely to cause leakage.

For very large lead tank outfits a double system of the supporting construction shown in Fig. 11 is used, but with individual stringers for each cell.

Glass cells are often set on wooden trays, which are filled with sand to distribute the strains and absorb the drip. Saw-dust was also used, but it becomes carbonized by the acid drip, and as this is likely to cause leakage, it has been abandoned.

In connecting the cells, which are usually put in series, great care should be taken to join the positive terminal of one cell to the negative of the next and so on. The color of the plate is the best indication of its polarity, the positive plate being a light brown when discharged and a chocolate color when charged, while the negative varies from a dark slate to a light slate color.

It may be noted at this point that the nomenclature, concerning storage batteries, is different from that of primary cells. The positive plate in the former is the peroxide plate (brown) and is that one from which the current flows out in discharging, whereas that would be the negative plate of a primary battery.

The positive pole or terminal in a storage battery is an extension of the positive plate, and is connected to the positive terminal of the dynamo in charging; consequently there is much less cause for confusion of terms than there is in the primary cell.

It is well to test the polarity of each cell and of the circuit before making connections. This may be done with any form of pole tester, or by the positive expedient of dipping the two terminals in dilute sulphuric acid, the one from which the most bubbles arise being negative. The connections should be scraped clean and

screwed up very tight, as they are much exposed to corrosion. The most satisfactory way to connect up a cell is to weld or "burn" the positive terminal to the negative terminal of the next cell, though soldered connections are very good.

This soldering is done as follows: Two strips of lead and the terminals to be connected are very carefully cleansed; the lead strips are then clamped to the terminals, a mold placed around the joints and molten lead poured into it.

**The Electrolyte.** Practice varies considerably as to the strength of solution to use. Chemically pure sulphuric acid is poured into water until its density becomes about 1.2, and then the mixture is allowed to cool; before pouring it into the cells, the electrolyte should completely cover the plates. Cells used in vehicle work use an electrolyte with density as high as 1.3. It is important to use perfectly pure acid and water, as impurities will cause local actions and ultimately destroy the plates.

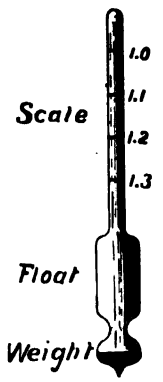


Fig. 12. The Hydrometer.

It is well to remember that water should never be poured into sulphuric acid, as it is likely to cause the liquid to be thrown out violently.

The advantage of a strong solution is its lower resistance; but it is likely to produce the very objectionable effect of "sulphating."

The density of the electrolyte falls immediately after filling a cell, since some of the acid is taken up by the plates; but it rises again in charging; for example from 1.17 to 1.2. It is convenient to keep a hydrometer in several cells to observe the density of the electrolyte, not only at the beginning, but as a permanent indicator of the amount of charge and general working conditions.

The hydrometer is an instrument for determining the specific gravity of a liquid, and consists of a weighted bulb and an upright glass rod, bearing a scale, the middle or unit point being the distance to which it sinks in pure water at 4°C. Readings above this point are for solutions of lower specific gravity than water, and those below it are for solutions of a higher specific gravity. For storage battery work the specific gravity of the electrolyte is

always between 1.1 and 1.3, hence we require only a certain portion of the scale as represented in Fig. 12.

**Charging.** The charging should begin immediately after a new cell is filled with the electrolyte, otherwise the plates are likely to become "sulphated." The first charge differs from subsequent regular charges in that it should be at a rate (lower than normal) that will not cause the temperature of the cell to reach 100°F, but in all other respects it is the same.

**Indications of Amount of Charge in a Storage Battery:**

1. The E. M. F. rises from 1.7 volts, which is the minimum value to which a lead cell should be discharged, to approximately 2.5 volts when fully charged, although this value may be made a trifle higher or lower, depending upon the rate of charge and temperature of cell. The rise is quite gradual, but more rapid near the beginning and end of the charge, as indicated in Fig. 13. When the cell is fully charged, the E. M. F. becomes constant and the curve approaches a horizontal line as shown. The charging should then be stopped as any more energy passed through the cell is simply wasted in producing gases. The external voltage is higher in charging than in discharging because of the internal resistance of the cell and resulting I. R. drop, which must be overcome in charging.

The measurements of voltage should always be made when the current is flowing either in charging or discharging.

The E. M. F. on open circuit has little practical significance.

2. *If a record is kept* of the exact number of ampere hours of charge and discharge, the actual amount of energy in the battery at any time is known, due allowance being made for leakage and other losses. For this purpose any integrating instrument such as the Thompson recording wattmeter may be used.

3. *The density of the electrolyte* gradually rises during the charging operation, Fig. 13; the density when charged being about .025 higher than when discharged, there is a lag in the change of the density of the electrolyte, the acid not being absorbed or given off at once, therefore a little time should be allowed before taking any hydrometer reading as final.

4. *Bubbles of air are given off* freely when the battery is fully charged, since the material of the plates is then no longer

able to take up the oxygen and hydrogen which tend to be set free by the electrolysis; these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky white, particularly in a cell which has not been very long in use.

5. *The color of the positive plates* varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale

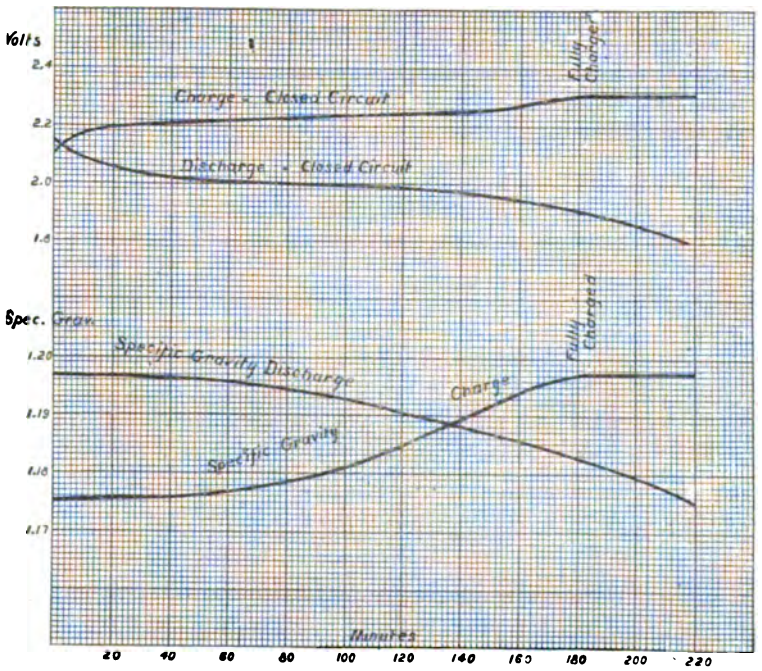



**Fig. 13. Curves Showing Variations in Sp. Grav. and Voltage in a Storage Battery During Charge.**

to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is acquired by experience, but is quite definite after one becomes familiar with a particular battery.

6. *Cadmium Test.* The apparatus for making this test consists of a small piece of cadmium, say $\frac{5}{8}''$ x $\frac{5}{8}''$ x $\frac{1}{32}''$ mounted as in Fig. 14. A glass tube contains the conducting wire, wax being used to protect the soldered joint of copper and cadmium. Cad-

mium is used because it will give reliable readings of the E. M. F. of the positive and the negative plates, with respect to itself. In this way a relative condition of the battery and also of each plate can be determined.

With normal conditions of cell, when fully charged and in open circuit, the difference of potential between the positive and the cadmium piece is 2.5 volts or nearly so, and between the cadmium and the negative plate is zero or nearly so. In fact it is sufficient if the sum of the readings is about 2.5 volts.

To avoid false conclusions in making a cadmium test, hydrometer, temperature and charge data should be noted. The cadmium test is usually made at the center of the cell to get a uniform current distribution. This test gives readings the sum of which is less than 2.50 volts, when hydrometer tests, temperature and charge data show that the cell is not fully charged; but if the hydrometer, temperature, and other data show the charge to be completed, and the cadmium gives .1 volt or more below 2.5 volts, the defective plate is readily determined by individual cadmium readings. For example, suppose we have a cell in which all conditions tend to show full charge but the potential difference is low. A cadmium test is taken and whichever plate shows the falling off from normal reading, that plate is the defective one, and should be examined for some of the troubles that will be discussed later.

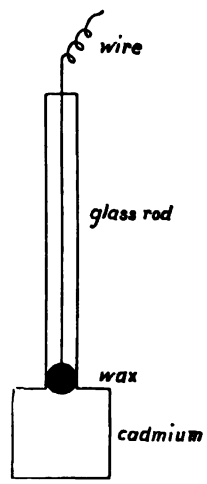


Fig. 14. The Cadmium Tester.

In some cases the cadmium reading with respect to both plates may approach zero; this is caused by a short circuit in the cell which should be found and removed immediately.

In practice it is advisable to have the cadmium wet before the test is made as the readings increase when cadmium is first placed in the electrolyte. The simplest way to accomplish this is to keep the cadmium tester in a beaker of distilled water when not in use. All foreign matter should be carefully removed from the cadmium as it might affect the results. If gas bubbles collect on the cadmium they should be taken off, as they tend to lower the readings.

The proper rate of charge depends upon the size and type of cell, and is usually specified by the manufacturer in each case, since it is merely an empirical fact, being determined by the construction of the plates.

The current for charging is ordinarily obtained from a direct current dynamo, but any other direct current source may be employed. The potential required for charging must exceed that of the battery, which, during the operation acts as a counter E. M F., the expression being $I = \frac{P - e}{R}$, in which I is the current, P the potential applied to battery terminals, $e$ the counter E. M. F., and R the internal resistance of the cell. Usually P is about .5 per

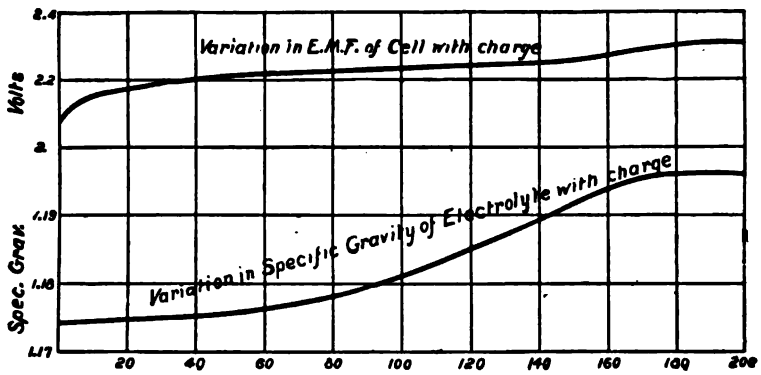



Fig. 15. Curve Showing Increase of E.M.F. in a Charging Cell.

cent greater than $e$, in order to cause the necessary charging current to flow through the resistance R of the cell.

In practice P is regulated until the required charging current I is obtained.

The above equation, put into form of $R = \frac{P - e}{I}$, enables the internal resistance R to be calculated, but as this varies considerably with the temperature, and with different states of charge, its exact value is not often considered.

Another form of the above equation, $e = P - IR$, shows that the true E. M. F. of the battery is less than the charging voltage by an amount equal to the product of the charging current and the internal resistance. Conversely, in discharging, the total

E. M. F. of cell is greater than the difference of potential P between its terminals by the same amount, that is, $e = P - IR$. Hence it is necessary to know I and R, or to measure the voltage when the circuit is open (in which case $I = O$), in order to find the real E. M. F. of cell. This applies to each individual cell as well as to the entire battery, and is important in determining the amount of charge or working condition of a particular cell.

If the charging voltage P be kept constant, it is evident from the above equtations that the current I will gradually decrease, since the C. E. M. F. or *e* of the cell steadily rises as shown in Fig. 15. This effect is counteracted somewhat by the fact that the internal resistance R also diminishes, owing to the density of the electrolyte increasing. This gradual reduction in the strength of the charging current is considered desirable by some authorities, since it enables the cell to take a greater charge than if the current were maintained at full strength. On the other hand, this diminishing charge makes it difficult to keep account of the exact number of ampere hours supplied to the cell; hence in ordinary commercial work it is considered simpler to charge with a constant current, and if it is desired to keep the cell temperature down, the current is decreased near the end of the charge. The charging operation may be continued until the battery is fully charged as shown by the indications already stated. Since most types of cells are not injured by a slight overcharging at a moderate rate it may even be carried a little beyond the charged point, as it tends to remove "sulphating." A considerable overcharge should be avoided as it causes excessive formation of gas bubbles in the active materials, is likely to heat the cell and even cause disintegration and buckling of the plates.

**Discharging.** A storage battery is in most cases discharged within a few hours after being charged, as, for example, in electric lighting, when the engine and dynamo are run during the day for charging the battery which supplies current to the lamps during the night. But a portable battery for feeding lamps might be required to retain its charge for several days. A certain loss of charge occurs in any battery, amounting to about .8 per cent in one week, but for one day or less it is quite small.

Even when the discharge occurs immediately, the average

voltage and the ampere-hours obtained are less than for the charge, as explained under "Efficiency." The loss referred to is additional, depending upon the time.

The operation of discharging is naturally the converse of charging, the changes which have been described as occurring in the latter take place also in the former, but in the reverse order. The normal rate of discharging is usually equal to that of charging, but may be somewhat greater. In some cases it is necessary to discharge at higher rates, but by so doing a percentage of the capacity in ampere-hours is sacrificed.

For example, a cell whose normal or eight-hour discharge rate is 100 amperes, can easily be discharged at 400 amperes for one hour, but only 50 per cent of the cell's capacity in ampere-hours is obtained at the latter rate.

An excessive discharge rate is injurious to most types of storage battery plates since it tends to disintegrate the plates, and abnormally heats the electrolyte, which hastens the disintegration; it is therefore advisable to protect the battery with fuses or an automatic circuit breaker.

A storage battery *should never be discharged completely*, as it is very likely to become "sulphated," or otherwise injured; and moreover the E. M. F. falls so rapidly towards the end of discharge that the current would be of no practical value. The limit of discharge is usually considered to be the point at which the E. M. F. drops to 1.75 volts, though when cells are used at the one-hour rate the limit of discharge is 1.6 volts.

The charge usually left in a storage battery is from 10 to 30 per cent of the total capacity, depending on the rate of discharge, but this involves no considerable loss of energy or efficiency, since it remains in the battery each time and the charging begins at that point.

**The Efficiency of Storage Batteries.** The efficiency of any apparatus is the ratio between what it gives out and that which it consumes. In a storage battery it is the ratio of the amount of discharge to what is put in to bring the battery back to its original condition after a discharge. While this seems extremely simple and definite there are several opportunities for confusion or quibble when applied to a secondary battery.

In the first place, the "ampere efficiency" or more properly "ampere-hour efficiency" and which is the ratio of current in ampere-hours drawn from the battery to current in ampere-hours put into the battery is quite different from the watt-hour efficiency. The latter is the real efficiency, since it considers the energy, and includes the voltage as well as the ampere-hours. Ampere efficiency may be scientifically interesting as showing the action of a battery; but it is not of much commercial importance. This is likely to be used either through ignorance or intention to give a false idea since the ampere efficiency is often 15 per cent higher than the watt efficiency.

Another difficulty with the ampere efficiency is the fact that it is possible to obtain an apparent efficiency of over 100 per cent from a storage battery. Since a certain amount ($33\frac{1}{3}$ per cent) of charge is always left in the cell, it is possible to draw apparently more ampere-hours of current than were put in it, by simply discharging the cell more than usual.

This matter has been investigated by Ayrton, who states:

"If an E. P. S. accumulator be over and over again carried around the cycle of being charged up to 2.4 volts, and discharged down to 1.8 per cell, the charging and discharging currents being the maximum allowed by the makers, viz., .026 ampere per square inch of surface in charging, and .029 ampere per square inch in discharging, the working efficiency thus obtained may be 97 per cent for the ampere-hours, and 87 per cent for the watt-hours. If, on the contrary, the cell be constantly charged up before being tested, then for the first few charges and discharges between the above limits, and with the same current density in charging and discharging, even the energy efficiency may be as high as 93 per cent; whereas if the accumulator has been left for some weeks, then, although it was left charged, the energy efficiency for the first few charges and discharges will be as low as 70 per cent."

In general practice it has been found that the efficiency of storage battery plants, when in good condition, varies from 75 to 80 per cent. For instance, referring to the battery plant at the Edison Electric Company station in Boston, a series of tests made there shows the battery installation to have an efficiency of 75 per cent.

**Depreciation of Accumulators.** The depreciation is claimed to be as low as 5 per cent per annum; in fact both the Tudor and Chloride battery installations at the Boston Edison Company's plants are insured and kept in repairs by the makers for 4 per cent per annum of their total original cost. This figure is as low as the maintenance of the very best steam or electrical machinery. One of the largest electrical manufacturing companies in this country has in use a storage battery equipment which, for the past eight years, has not cost a cent in the way of repairs to, or renewals of, plates. On the other hand, the life of storage batteries in traction or automobile work has in some instances not exceeded six months, though it is claimed that these cells were only in an experimental stage. One must be somewhat guarded, however, in accepting low figures of this kind since from their nature the plates are very easily injured and difficult to repair. It would be very unwise for any one to purchase a battery without the makers' guarantee, to allow less than 10 per cent for its annual depreciation, and this does not include interest, taxes, or other fixed charges.

It has been the practice of several storage battery manufacturers to insure their battery equipments for 6 per cent per annum of their first total cost; this insurance was a maintenance contract calling for inspection and any repairs necessitated through normal use of cells.

## TROUBLES AND REMEDIES.

The most serious troubles which occur in storage batteries are sulphating, buckling, disintegration and short circuiting of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

**Sulphating.** The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate ($PbSO_4$) on both plates when they are discharged, their color being usually light brown and gray, due to presence of the $PbO_2$ still on the positive plate. But under certain circumstances a whitish scale forms on the plates, probably consisting of $Pb_2SO_5$. Plates thus coated are said to be "sulphated." This term is, therefore, somewhat ambiguous, since the formation of a certain

proportion of ordinary lead sulphate ($PbSO_4$) is perfectly legitimate, but the word has acquired a special significance in this connection.

A plate is inactive, and practically incapable of being charged, when it is covered with this white coating or sulphate, as it is a non-conductor.

The conditions under which this objectionable sulphating is likely to occur are as follows:

(*a.*) A storage battery may be overdischarged, that is, run below the limits of voltage specified, and left in that condition for several hours.

(*b.*) A storage battery may be left discharged for some time, even though the limits have not been exceeded.

(*c.*) The electrolyte may be too strong.

(*d.*) The electrolyte may be too hot (about 125° F).

(*e.*) A short circuit may cause "sulphating" because the cell becomes discharged (on open circuit) and when charging it receives only a low charge as compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time on account of leakage of current due to defective insulation of the cells or circuit, or the plates may become short-circuited by particles of the active or foreign substances falling between them.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells for a number of times, the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; when the cells are very badly sulphated, the charging rate should be about $\frac{1}{4}$ the normal rate for three days.

According to the electrolyte a small quantity of sodium sulphate, or carbonate, which latter is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the unhealthy sulphate. This is not often used in practice, as a cell must be emptied, thoroughly washed and fresh electrolyte added after the plates have been rested to proper condition before the cell can be used to advantage.

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be moved. It also produces the following trouble:

**Buckling,** or warping of a plate; is caused by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, it may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate in this way, a wooden mallet should be used very carefully, with flat boards laid under and over the plate. Buckling may be caused by an excessive rate of charging or discharging, as well as by sulphating.

**Disintegration.** Some of the material may become loosened or entirely separated from the plates, as a result of various causes. The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material may take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type containing plugs or pellets of lead paste.

The fragments which fall from the plates not only involve a loss of material, but are also likely to extend across or gather between the plates, and cause a short circuit.

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make, therefore it is to them that special attention should be directed in the management of storage batteries.

**Short Circuiting** of cell may be caused by conditions previously stated and also by the collection of sediment at the bottom

of the containing cell. The short circuiting caused by the dropping in of foreign matter, or the bridging of the active materials, is prevented by the use of glass, rubber or wooden separators.

The short circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch, in large cells it is considerable, being about 6 inches, and on account of the weight of large sized plates they are supported at the bottom by glass frames running lengthwise through the cell, as shown in Fig. 16.

This sediment should be watched carefully and when it reaches a depth of 1 inch or more at the center of the cells, it should be removed. The usual method is to take out the plates, syphon the electrolyte off carefully, and then flush out the tanks until all the sediment is removed. If syphoning cannot be resorted to, due to absence of drop, a pump may be used, either of glass or of the bronze rotary type.

**Troubles from Acid Spray.** An accumulator gives off occasional bubbles of gas at almost any time or condition; but when nearly charged, the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough.

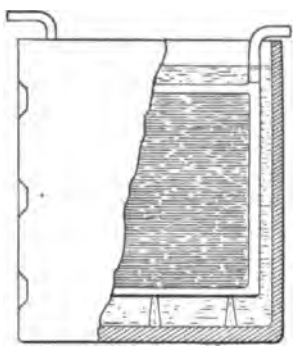


Fig. 16. Glass Frame Support Used to Prevent Short Circuiting by Sediment.

Glass covers are sometimes placed over cells to prevent the escape of fumes, but this is not advisable as the glass becomes moist and will collect dust, thus forming a conducting surface over the cell.

Attempts have been made to do away with this spraying by placing an oil film (thin layer of oil) over the electrolyte, but this has the objection of interfering with hydrometers; in addition it sticks to the surface of the plates when they are removed, and interferes with their conductivity on replacing them.

Another plan consists of spreading a layer of finely granulated cork over the surface of the liquid, but while this does not interfere with the hydrometer, it makes the cell look dirty.

The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes, in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust.

In connecting up the cells, it is advisable to use lead-covered copper cables, as this covering protects the copper, and prevents the dropping of copper salts into the cell.

**The Purity of the Electrolyte** is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when "formed" (Planté) plates are used, and some chloride, when "Chloride" negatives are used. In addition, iron may be present due to the water or acid; if the sulphuric acid is made from iron pyrites; it may even be present, owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly some of the copper salt formed from the connections by this corrosive action may fall into the cell. Mercury may also be present due to the breakage of hydrometers or thermometers.

Other foreign substance might be present, but those named are the most harmful.

Nitric acid even in exceedingly small quantities will cause disintegration of plates, as the supporting material is destroyed.

Chlorine has a similar effect.

Iron, mercury and copper produce local action, and thus decrease the efficiency and ultimately the life of the cells.

The electrolyte should be tested about once a week for these impurities, and if any of them are present, it should be drawn off and renewed. If nitric acid is present, it is even advisable to flush the cell with pure water.

## TESTS.

1. **Test for Chlorine.** To a sample of electrolyte in a test tube, add a few drops of silver nitrate solution; if a curdy white precipitate forms, an excess of ammonia is added, and if this dissolves the precipitate, chlorine is present in some form.

2. **Test for Iron.** Iron may appear in one of two forms, namely, ferrous or ferric salts. A small sample is taken and some concentrated hydrochloric acid added and then some potassium ferric cyanide; if a heavy blue precipitate forms, ferrous iron is present; if in very minute quantities, a deep blue green discoloration results.

3. **Test for Ferric Salts.** To a sample add some ammonium thio-sulphate; if a blood red solution or precipitate is the result, ferric iron salts are present.

4. **Test for Copper.** To a sample of electrolyte an excess of ammonium hydrate is added; if a rich blue solution is the result, copper is present. It is advisable to check the test by taking another sample and adding some potassium hydrate to it; if a blue precipitate is found which turns black upon boiling, it is additional proof of the presence of copper.

5. **As Nitric Acid** is injurious even in very small quantities, it is advisable to make the following test, which is very sensitive. Some diphenylamine in concentrated sulphuric acid is added to the sample; if a deep blue color is the result, nitrates or nitrites are present.

6. **Test for Mercury.** Mercury may be present in two forms, mercurous or mercuric compounds. The *mercurous* compounds give a black precipitate with lime water, and a greenish precipitate with potassium iodide.

The *mercuric* compounds give a yellow precipitate with lime water, and a red or scarlet precipitate with potassium iodide.

On account of these possible difficulties, the following is recommended:

1. Test every carboy of sulphuric acid before using.

2. Concentrated sulphuric acid should not be kept around as it may be used by mistake, which would ruin the plates.

3. Only distilled water from carboys should be used and not barrels as it may be contaminated from the organic material of the barrels.

4. Water from the city mains is never to be used unless iron is very low.

5. When testing with hydrometer for acid strength (specific gravity) the battery should be fully charged and tests always made at the same temperature.

**Putting the Battery out of Commission.** If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given.

It frequently happens in practice that a storage battery equipment is put out of commission for a lengthy period, (for instance, in large summer or winter resorts the battery may be used for one half of the year only). In such cases the procedure is as follows: First give the battery a complete charge at normal rate, then syphon off the electrolyte into carefully cleaned carboys (as it may be used again), and as each cell is emptied, immediately refill it with pure water. When the acid has been drawn from all cells and replaced with water, begin discharging the battery and continue until the voltage falls to or below one volt per cell at normal load (rate); when this point has been reached the water should be drawn off. In this condition the battery may stand without further attention until it is to be again put into service, and to do this proceed in the same manner as when the battery was originally put into use.

If during the discharge, when the water has replaced the electrolyte, the battery shows a tendency to get hot (100°F,) add colder water.

**Commercial Application.** The function of a storage battery is to receive electrical energy at one time or place, and to give it out at some other time or place.

The principal uses are the following:

1. To furnish portable electrical apparatus with power.

2. To make up for fluctuations, and thus steady the voltage and current.

3. To furnish energy during certain hours of the day or night, and thus enable the generating machinery to be stopped.

4. To aid the generating plant in carrying the maximum load (peak) which usually exists for only an hour or two.

5. To make the load on engines or prime movers more uniform, by charging the battery when the load is light.

6. To transform from a higher to a lower potential by charging the cells in series, and discharging them in parallel, or vice-versa.

7. To subdivide the voltage, and enable a three or a five wire system to be operated from a single generator.

Fig. 17. Gould Portable Storage Battery.

8. To supply current from local centers or substations.

9. To supply current to electrically driven vehicles.

10. As sources of current in telephone and telegraph systems.

11. For car lighting purposes.

12. As sources of constant potential and current in electrical laboratories.

**Portable Storage Batteries.** The storage battery is practically the only means of supply for portable electric lamps, or those not connected to a dynamo even when they are not portable. The prime battery is expensive and troublesome to operate; and has never been commercially successful for electric lighting or power, except where only a very small amount is required. Nor is there any other satisfactory primary source of electrical energy except the dynamo driven by mechanical power. It is therefore practically essential to adopt storage batteries wherever portable electric motors, lamps, etc., are used.

The various manufacturers furnish portable forms of storage batteries: for example, the Gould Storage Battery Company's portable battery (Fig. 17) is arranged in a case made as a hard rubber jar, lead-lined box or glazed earthenware jar, over which is placed a rubber gasket, and then a wooden cover clamped in place by U shaped straps, passing around the containing vessel. For ventilation in charging, the cover has threaded holes which, when the battery is in use, are closed with hard rubber stoppers. The usual number of cells in a case is from one to five, although they are made up in larger numbers if desired. The batteries are rated at 2 volts per cell.

A serious objection to portable storage batteries is their great weight. For example, a standard size weighing 100 lbs. yields 5 amperes at ten volts, or fifty watts for ten hours: just enough to feed a 16 C. P. lamp. The total discharge is 500 watts-hours or two thirds of one I. H. P. hour. The special forms of battery used in automobiles give about twice this output for the same weight.

This weight is almost prohibitive to portability except for automobiles, railway train lighting and special purposes.

Portable batteries, for example, are used for feeding small motors lamps, etc. for medical or dental purposes, in which cases their weight is not a serious difficulty in view of the importance

of the work, and the small amount of energy required. Another special field for very small batteries is the theatrical application for which they are carried by the performers. Storage batteries are also being extensively used as source of power to drive small fan and kinetoscope motors.

**Storage Batteries for Preventing Fluctuations** due to unsteadiness in the driving-power or in the load, as with elevators, are often applied successfully. A dynamo driven by a gas-engine, for example, may vary periodically in speed because of the explosive action of the gas in the cylinder; and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. A storage battery is generally installed in connection with a small gas or steam engine lighting plant to enable the engine to be stopped for a considerable portion of the time, and thus save labor and attention, in which case the battery may also act to prevent fluctuations. A windmill electric-lighting plant must have an accumulator or some other means of storing energy, not only to eliminate fluctuations in speed which are continually occurring, but also to bridge over the considerable periods of calm weather.

**To Furnish Energy During Certain Portions of the Day or Night.** In almost every electric-lighting plant, there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

For example, Fig. 18 is a load diagram showing the weekly output of the electric plant of the Astor Building in New York City. The generator plant runs from 3 A.M. to 8 P.M. each day, the battery being charged from 3 A.M. to 11 A.M.; and when the generating plant is shut down at 8 P.M. the battery carries the entire load from then until 3 A.M., when the plant is started up again. Saturday nights the plant is shut down at eight o'clock, and the battery furnishes all the power required from then until Monday morning at 3. This enables the plant to be operated by two gangs or shifts; practically no labor being required for the remaining seven hours as the battery carries the load, and the machinery is stopped entirely all day Sunday, giving a stretch of thirty-one hours once a week and seven hours each

night for cleaning and repairs. In a hotel, residence or on board a yacht, it may be desirable to stop the machinery and avoid the vibration and noise during the night.

**Storage Batteries to Aid in Carrying the Maximum Load.** Assume in the case of the load diagram shown in Fig. 19, that the generating machinery is capable of supplying 8,000 kilowatts and that an accumulator is used to furnish the remaining 3,600 kilowatts at the time of maximum load, that is, the "peak" of the load diagram. This simply means that batteries are substituted for a certain portion of the machinery plant, and the question is whether or not the substitution is of any advantage.

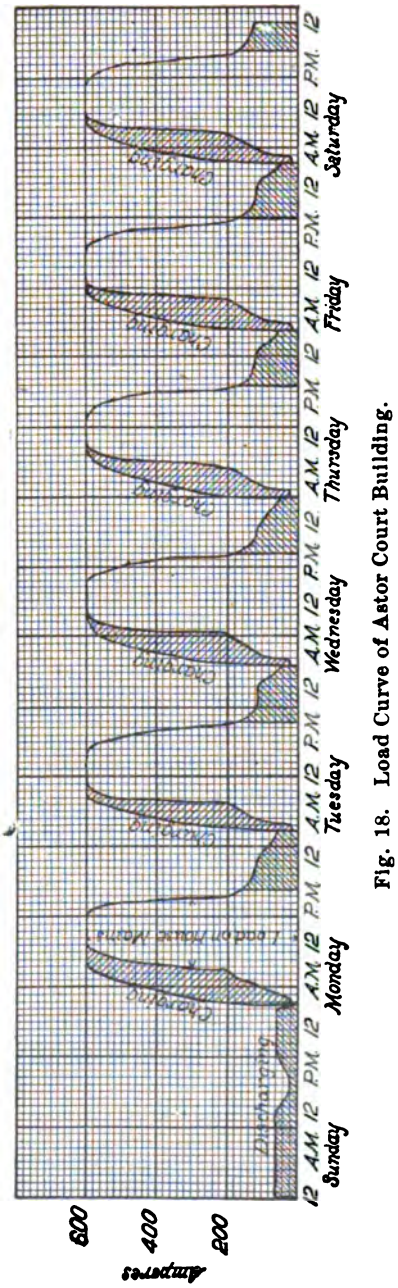



Fig. 18. Load Curve of Astor Court Building.

The first cost of a battery for a given rate of output depends simply upon the time of discharge. Most accumulators have a normal period of discharge of about 8 hours, at which rate the price of accumulators to furnish a given number of watts would be 3 to 5 times as great as that of the equivalent boilers, engines and dynamos combined, but if the time of discharge is reduced to about 2 or 3 hours, the costs are about equal and with a still higher rate the cost of batteries would be less.

As a matter of fact, the storage battery secures other advantages so that the total gain may be very important. For example, there is a reserve supply in case of accident and the load may be made more uniform as will now be explained.

**Storage Batteries to Maintain Uniform Load on Engines.** Steam engines are very inefficient at light loads, and this fact often causes serious losses especially in electric-lighting plants. Judicious selection of the number and sizes of the engines enable them to be worked in most cases at a considerable fraction of their full capacity nearly all of the time. Nevertheless, the storage battery gives greater flexibility to the plant, and renders it easy to increase the economy of the engines by making their loads

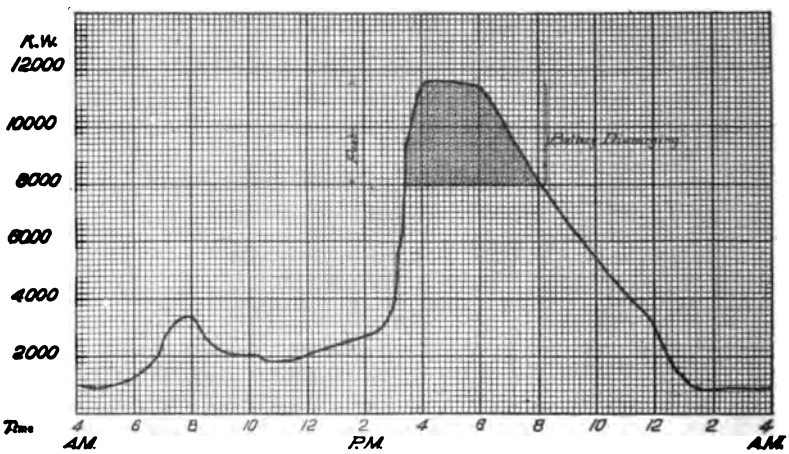



Fig. 19. Load Curve Showing "Peak" of Load Carried by Storage Battery.

still more uniform, and nearer to their full capacities while they are running. The engines can be made to have a uniform full load, the battery being charged when the external load is light, and the battery taking the peak of the load when it is heavy.

**Storage Batteries Used as Transformers.** If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage will be required for charging, and a low voltage will be given out. The amounts of energy measured in watt hours are the same, less the loss of about 25 per cent which always occurs in accumulators; the result is similar to that obtained by an alternating current transformer or motor-dynamo

but is less efficient. As an example the equipment used at the Brooklyn Navy Yard may be mentioned. It consists of about 250 small cells connected up in series parallel of 5 sets of 50 cells each and charged on a 110 volt circuit. When discharged they are connected up all in series and give about 500 volts but with very small current. This equipment is used to furnish 500 volts for the "insulation test" of cables and therefore requires little or no current.

**Storage Batteries Used for Subdividing Voltage.** The most important practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three wire system being supplied from the battery, the neutral wire of which

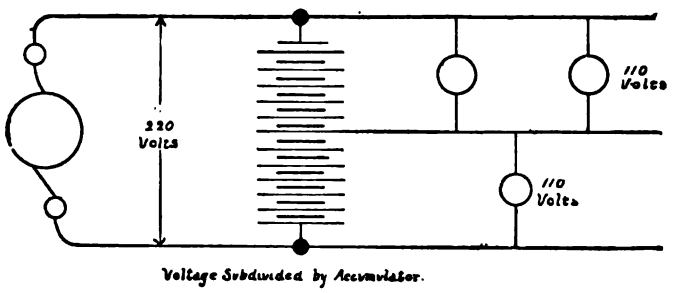



Fig. 20. Battery used to Sub-divide Voltage.

is connected to the middle point of the battery as represented in Fig. 20. This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a sub-station near the district to be supplied, so that it is only necessary to run two conductors to that point instead of three. The same principle may be applied to the five-wire system.

The Hartford Electric Light Company was one of the first in this country to introduce the modern method of high tension transmission, with low-tension 3 wire distribution.

The auxiliary battery used in connection with this equipment consists of 130 Chloride Accumulators (65 on a side) each cell containing 31 negatives and 30 positive plates, each 15 $\frac{1}{2}''$ x 31", placed in lead lined tanks measuring $58\frac{1}{4}$ x $21\frac{1}{2}$ x $43\frac{7}{8}$ inches. Fig. 21 is a diagram showing the general plan of the system. The power is transmitted 10.8 miles from the Farmington River

Power Station to the Pearl Street Station, in Hartford, by means of step-up transformers, a ten thousand volt transmission line, and step-down transformers for distribution. From Pearl Street Station to State Street, a distance of three thousand feet, the current is transmitted at twenty-four hundred volts, at which latter point, by means of step-down transformers and rotary converter, the storage battery is charged and the current distributed over a low tension three wire system.

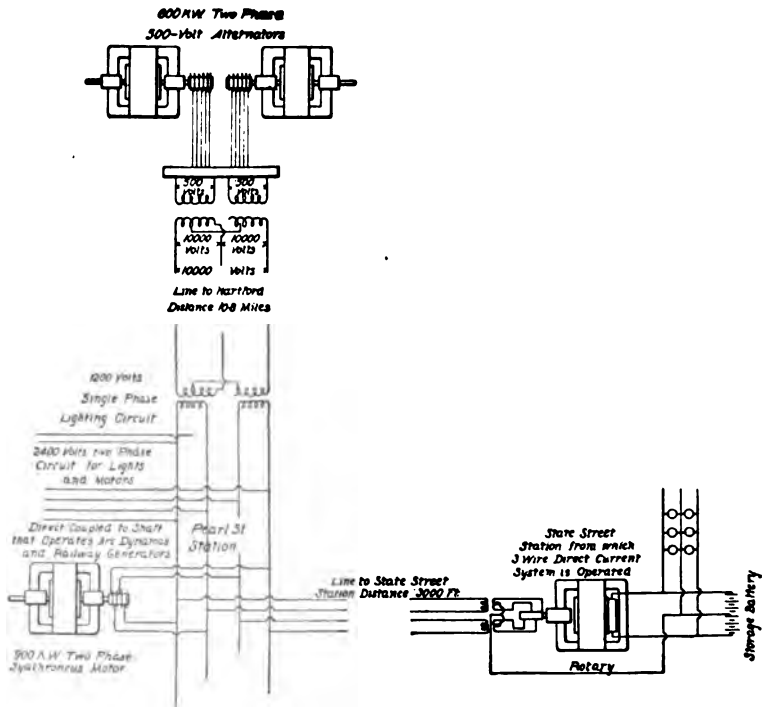



Fig. 21. Plan of the Farmington River — Hartford Distribution System.

**Storage Battery for Sub-Stations.** The plan of installing battery plants at local centers, which are charged from the main station, enables some of the conductors to be saved in a three (or five) wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum cur-

rent consumed by the lamps, etc. which may be several times its average value. The generating machinery has the same steady load as if the battery were located near it.

The batteries at the various sub-stations may be connected and charged in series or in parallel. The former plan would require far less copper in the conductors since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this great difference of potential would exist between the first and the last batteries of the series and if either of these became grounded, any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage.

An excellent example of the storage battery sub-station is the Bowling Green Plant of the New York Edison Company the description of which is as follows: The Bowling Green Station furnishes an auxiliary supply of current directly from the battery, enabling the feeders, extended as tie feeders into the Bowling Green building, to be used as distributing feeders to the system from both the Duane Street and Bowling Green Stations. While acting as an auxiliary supply to the general system, the battery also takes care of the distribution of current to the extensive installation in the Bowling Green Building itself. The supply of current to charge the battery is taken from the Duane Street Station, about a mile distant, over four tie feeders equipped with controllable disconnective switch boxes on the Bowker-Van Vleck system. This enables them to be used as tie feeders by disconnecting them from the general system during the hours of light load, and as distributing-feeders during the hours of maximum load, when they feed current into the system from each end. A considerable saving is thus effected in the investment because costly feeders are not required to supply the maximum load to a distant part of the system.

This installation of an auxiliary source of current supply in the lower district makes it possible to shut down the generators in the Duane Street Station during the hours of minimum load, the supply of current to the district below 8th Street being derived from the battery plants at Bowling Green and 12th Street Stations, supplemented, if desired, by the supply of current from

the 26th Street Station over the tie lines to 12th Street Station, whence the current is distributed through boosters raising it to the required potential, over the tie feeders to the Duane Street Station switch board. The battery and operating rooms of the Bowling Green Station are located in the sub-basement of the Bowling Green Office Building. Vitrified hollow tile for conducting the feeder cables are laid under the battery room floor, which consists of glazed white tile. Drains to carry off the water or acid run in the aisles between the cells and lead to small cesspools which discharge into a lead drain pipe.

The battery consists of 150 Chloride cells, seventy-five in series on each side of the three wire system. The cells consist of wooden tanks, $40\frac{3}{4}$ by $21\frac{1}{2}$ by $30\frac{1}{2}$ inches, treated with an acid proof paint and lead lined, each containing 14 positive and 15 negative plates $15\frac{1}{2}$ inches wide by 31 inches high. Each tank is supported on four petticoat porcelain insulators resting upon 6-inch glazed tiles.

The plates are suspended in the tanks by shoulders resting upon sheets of heavy glass, which stand upon lead saddles in the bottoms of the tanks. The cells are connected by welding the plate terminals to lead bus bars, no mechanical connections being used.

Twenty of the ends cells on each side of the system are used for regulating; being separately connected to contact points on the regulating switches, which carry movable contacts operated by a screw. The potential is raised or lowered by cutting in or cutting out the regulating cells. Two regulating switches are connected in multiple on the positive and two on negative sides to permit of discharge at two potentials, or to enable the battery to be charged and discharged simultaneously. The conductors between each series of cells, and between the regulating cells and the regulating switches, consist of copper bars 3 inches wide by $\frac{1}{2}$ inch thick. These bars are supported on porcelain insulators resting in hangers.

The connections of this equipment are shown in Fig. 22.

The capacities of the battery at various rates of discharge are:

2000 amperes per side for 1 hour.
1000 amperes per side for 3 hours.
400 amperes per side for 10 hours.

Provision has been made in the battery-room for the installation of a duplicate battery, which can be placed over the present plant. The booster is used to raise the voltage from that of the system to that required for charging the battery. The booster can be used also to raise the voltage of discharge for feeding some distant point of the system at a higher potential than would be normally required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two

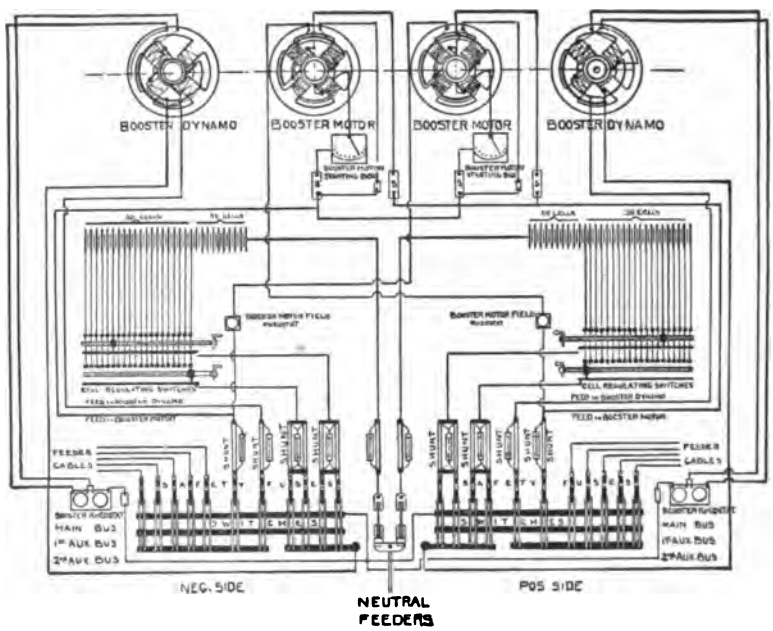



**Fig. 22. Connections of the Bowling Green Storage Battery Sub-station.**

motors. Each dynamo has a capacity of 1200 amperes and a range of pressure up to 60 volts.

**Storage Batteries Used for Two or More of the Above-named Purposes.** Each of the different uses has been considered separately to avoid confusion, but in most cases the storage battery is adopted in order to secure several advantages. By thus combining different applications the plant is rendered not only more economical, but also more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load, or when the latter is partially or wholly dis-

abled. It often happens that it is difficult to produce or maintain sufficient steam-pressure, owing to poor draft or other conditions, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it, temporarily, in order to make some repair or adjustment. It is also possible to feed some of the circuits from the battery while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways the storage battery may be a convenient adjunct to an electrical system. The fact that it is so radically different from the machinery in its nature and action makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam-piping, for instance, might shut down all the machinery, but probably it would not affect the battery; and, vice-versa, an accident to the latter is not likely to extend to the former.

As an example of this application of the storage battery to several purposes, the following case may be cited:

The installation of storage batteries at the power house of the Woronoco Street Railway Company, in Westfield, Mass., presents features of special interest. After considering various methods of increasing the power-house capacity, rendered necessary by the construction of an extension of the line, it was decided that the storage battery offered the greatest advantages.

The station equipment consists of two 75-KW. multipolar generators belted to two 120 H.P. high-speed, simple, non-condensing engines, steam being furnished by two 90 H.P. return tubular boilers.

The battery consists of 264 cells of the "Chloride Accumulator," Type F–11, in glass jars of Type F–13, permitting an increase of 20 per cent by the addition of one pair of plates in each cell, and is installed in a small brick extension to the power house. The cells are located in one tier, each cell being supported on a sand tray resting on four glass insulators. The foundation for each row of cells consists of two stringers of wood suitably braced and supported on brick piers. This battery was not in-

stalled as a voltage regulator, the feeder system being so designed that the drop on the line is only a small amount.

By means of the battery the load on the machinery is reduced within the capacity of one unit, leaving the second one as a reserve in case of an accident or an unusually heavy load. Without the battery both machines would be needed nearly all the time.

The economy of operation, due to using one unit instead of two, is clearly shown by the following station records.

| | Date, 1899. | Lbs. coal. | Output kw.-hrs. | Lbs. coal. per kw.-hr. |
|---|---|---|---|---|
| With battery | Oct. 25-27 | 16,250 | 3,032 | 5.36 |
| Without battery | Oct. 28 | 6,250 | 981 | 6.37 |

This shows an increase in the coal consumption of 19 per cent. on the day when the operation of the battery was discontinued. The plant is also noteworthy from the fact that the station attendance is reduced to one man per shift, the engineer doing his own firing. This arrangement could not have been continued under the conditions of increased load, had it not been for the improved regulation and reduction of coal handling, and especially the increased reliability of operation secured by the battery.

On several occasions the battery has been called upon to carry the entire load of the system for an hour or so, during a temporary shut-down of the rest of the plant, as well as early in the morning or late at night, when only one or two cars are in operation.

**Storage Batteries for Propelling Vehicles and Boats.** . The storage battery is usually about 35 per cent of the total weight in the modern electric automobile, and even with this great proportion, the distance run on one charge is seldom more than from 20 to 40 miles at a speed of about ten miles per hour, and that only on comparatively smooth roads. The ordinary battery equipment consists of about 44 cells of 108 ampere-hours capacity with an average discharge voltage of about 1.9.

In cities or where the roads are good, with charging stations close at hand, the electric automobile is superior to the gasoline types, on account of the absence of explosive vapors, with the accompanying odor and noise. But for general touring they are not as handy on account of the limited capacity of the battery.

The application of the storage battery to the street car, while presenting such great advantages as the entire absence of poles and overhead wires, has not been a commercial success, mainly on account of the mechanical weakness of the plates, which are not able to stand the jolting and jarring or the rush of current due to frequent starts and stops. Another objectionable feature and one that caused trouble in New York City on the 34th Street crosstown line, is the escape of acid fumes into the car, producing throat irritations and coughs among the passengers.

The storage battery has been comparatively successful as a source of power in submarine boats, being charged while the vessel is on the surface, and discharged to run electric motors and lights when the vessel is manœuvering under the surface.

**Storage Batteries in Telephone and Telegraph Systems.** Since the adoption of the central battery systems by telephone companies, the use of the storage battery for this purpose has become very common, its advantages over the primary cell being as follows: Lower first cost, smaller space required (about $\frac{1}{4}$ of that occupied by an equivalent primary battery), greater constancy of E. M. F. and lower internal resistance, absence of the annoying "creeping salts," and rapidity of recharge. The cost of storage battery maintenance is about $\frac{1}{8}$ that of the primary cell.

In telephone work, the battery is installed in the district station, and charged when the line is not in use, from either a street connection or a generator in the station. When the line is in use for conversation, the charging current is automatically cut off, and the battery alone switched into service.

The storage battery in telephone work has become so important that the following description of a typical installation is given.

In the Filbert Street Exchange of the Philadelphia Bell Telephone Company there are two generating units, forming a duplicate plant, each consisting of one engine, directly connected to a 30 K. W., 110 volt dynamo. These machines are run on alternate days and are used for lighting the building and for furnishing power at 110 volts to various motor generators. The latter comprise two 1.5 K. W. machines for charging a 20-volt battery, one 1.5 K. W. machine for charging an 8-volt battery; one 500-watt machine for charging a 4-volt battery, and two $\frac{1}{4}$ H. P. 75-volt

alternating current motor dynamos for ringing call bells. Only one machine is installed for the 8-volt battery and one for the 4-volt battery. Both Batteries are in duplicate. To avoid a possible break down, a rheostat is furnished, so that the batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected by automatic cut-outs.

The 20-volt battery consists of ten "Chloride Accumulators" having a capacity of about 1,000 ampere-hours, which furnish all the current needed by the subscribers for talking and for calling up the central office. The 8-volt batteries, in duplicate, consist of four cells each having a capacity of 2,400 ampere-hours. This battery furnishes current for the "disconnect" signals on the operator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call, by plugging into the jack corresponding to the lamp signal.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging.

Each of the duplicate 4-volt batteries comprises six 13-cells arranged in two sets. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. The latter is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for the lamp signals which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call. This battery also is made in duplicate, one being charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

**Storage Batteries for Train Illumination.** When cars are lighted by oil or gas lamps, these, owing to their size, and the heat produced by them, can be installed only in certain places, so that the distribution of light is not general, besides which, the heat and odor given off by the lamps are objectionable. The in-

flammable character of the illuminants involves great danger of explosion or fire in case of a train wreck. The absence of these disagreeable and dangerous features in electric lighting, is what has made its application so desirable in traction work.

Several methods of electric illumination have been tried on railroad trains. In one of the simplest of these a small dynamo, on the locomotive truck, or one perched above the boiler, is driven by a small steam turbine. While this is an economical method, it has the objection, that when the locomotive is uncoupled, the cars must be illuminated by some other means.

For this reason, the storage battery system of supply has been adopted. A description of one of the most successful meth-

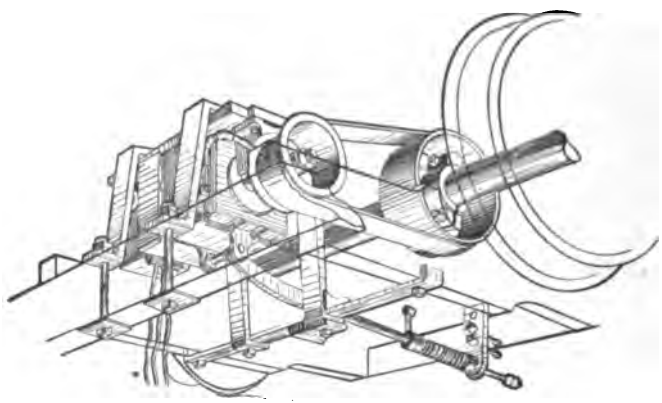


Fig. 23. Method of Suspension Used by the "Axle Light" System.

ods is as follows: The "Axle Light" System, as its name implies, derives the motive power for its dynamo from the car axle. The mechanism is suspended from the bottom of the car, and is completely encased, so as to be dust and water proof. It comprises a small dynamo driven from a pulley on the axle of the car by means of a friction coupling.

The dynamo and driving mechanism are shown in Fig. 23. The former generates from 32-40 volts, depending upon the speed of the train when the latter exceeds 15 miles per hour, the dynamo being then automatically connected to the battery and lamp circuit. An automatic device rectifies the direction of current, so that even though the direction of rotation is reversed, the battery

is always charged in the proper direction. A variable resistance in series with the field coils is automatically adjusted by a small motor, so that even at high speed the normal limit of voltage is not exceeded.

The lamps are 16 C. P. at 30 volts, the filaments being short and heavy so that they are not injured by vibration.

After the storage battery has been charged, it acts in parallel with the dynamo and avoids fluctuations in voltage. When the car stops, the dynamo is automatically cut out and the full supply of current is furnished by the battery, which is large enough for a ten-hour supply at full load.

**Storage Batteries for Electrical Laboratories.** The great advantage of this source of power in electrical laboratories, is the fact that any variation in their voltage is very gradual, and by the simple regulation of a rheostat in series with the battery, the operator can keep his voltage and current absolutely constant, while a test or calibration is being made. When a large current is wanted, as in the case of ammeter calibration, the cells may be connected in parallel, and discharged through a low resistance, thus cutting down the energy required for the test. A storage battery may also be used to step up the voltage, the cells being connected in parallel groups for charging and in series for discharging.

**Connection and Regulation of Storage Batteries.** The complete control of a battery in an electric-lighting plant requires provision to be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel; and it should be possible to charge the battery at the same time that lamps are being supplied. To accomplish these results requires three switches,— one to connect the battery to the dynamo, one to connect the lamps to the dynamo and one to connect the lamps to the battery. In some plants the second switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use. However, it would seem desirable to have all three switches in every plant in order to be able, at least, to supply lamps and charge the battery at any time. In the battery circuit there should be an amperemeter having a scale on both sides of zero, so that it shows whether the battery is being charged or discharged, as well as the

value of the current. Another similar amperemeter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third amperemeter is desirable in the lamp circuit, to show the total current supplied to the lamps; but it need only indicate on one side of zero, since the current there always flows in the same direction. A voltmeter is required with

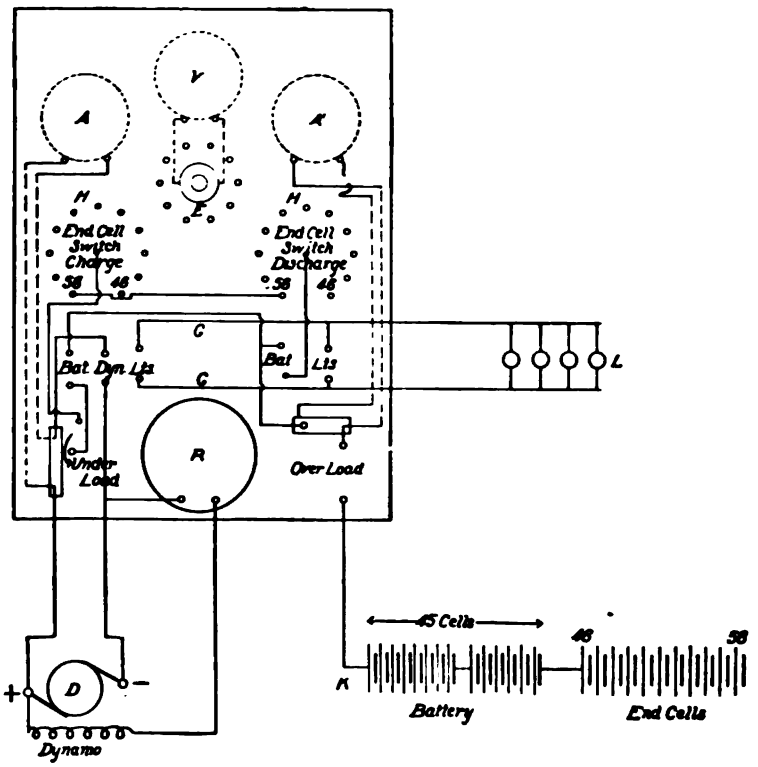



Fig. 24. Switchboard, Dynamo and Battery Connections.

a three-way switch, which enables it to be connected to the dynamo, battery, or lamps respectively.

An automatic overload switch must be inserted in the battery circuit so as to open or introduce resistance into the circuit when the current becomes excessive. An automatic cut-out is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from

any cause the E.M.F. of the latter drops below that of the former. This completes the ordinary measuring and circuit-controlling apparatus employed in connection with storage batteries. The arrangement is shown diagrammatically in Fig. 24, in which A and $A^1$ are the two amperemeters, the third one being omitted in this case; V is the voltmeter; E the voltmeter switch to connect to the dynamo, battery, or lamps as desired; G the bus bars; L, lamps; D, dynamo; R, rheostat in field-circuit of dynamo; S,

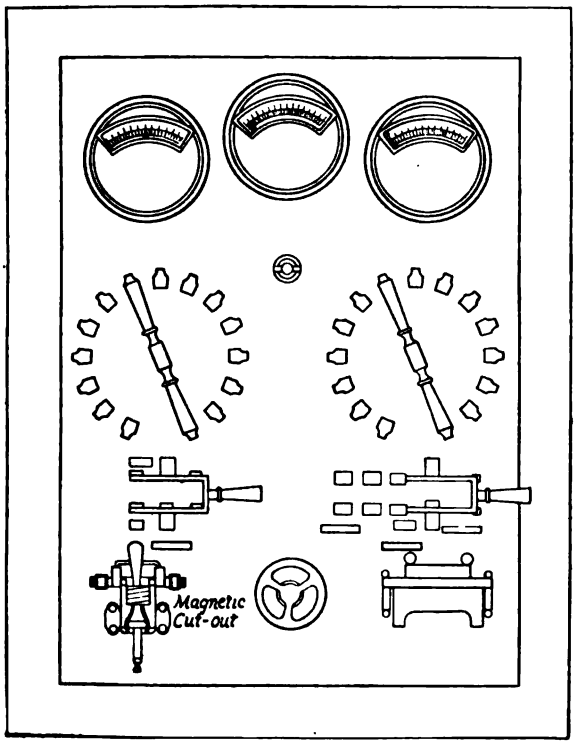



Fig. 25. Face of Switchboard.

switch, battery to lamps; S′, switch, dynamo to battery; S″, switch, dynamo to lamps direct; O, overload switch; C, automatic cut-out; K is the battery, and HH are the reserve-cell switches for regulation. Fig. 25 shows the switchboard with these devices mounted upon it.

**The Regulation of Storage Batteries** is one of the most

troublesome matters involved in their practical use. This arises from the fact that the voltage falls continually from the beginning to the end of discharge. To be sure, this decline is gradual; but its total value is large, being from about 2.2 to about 1.8 volts, which is a decrease of nearly 18 per cent.

In order to maintain a constant voltage, the usual plan is to have a number of extra cells, which are successively switched into circuit as the potential falls. These reserve cells and the switches which control them are represented at HH in Fig. 24.

The contact pieces of these switches must be made in such a way that they do not short-circuit the cells as they pass from one point to the next. This is accomplished by splitting the movable contact arm into two parts, between which a certain amount of resistance is introduced, so that when the two parts happen to rest on two adjacent contact points, the resistance prevents the cell which is connected to these two points from being short-circuited, and also avoids breaking the circuit.

The number of extra cells depends upon the conditions; for 110 volt lamps, it would require 51 cells to obtain 112.2 volts when fully charged and giving 2.2 volts each, assuming the drop on the conductors at 2 per cent. When the battery becomes discharged, and its potential falls to 1.8 volts per element, 10 additional cells or 61 in all, would be needed. These would yield 111.8 volts, assuming the average potential of the reserve cells to be 2 volts, since they have not been discharged to the same extent as the original battery. If the drop on the conductors is 10 per cent of the lamp voltage, the potential at the battery will have to be $110 + 11 = 121$. This will necessitate 4 more elements, or a total of 65 when the 51 original cells are fully discharged to 1.8 volts, and the 14 extra cells give 2 volts each.

For a three wire system the above figures should, of course, be doubled. This switching of extra cells into and out of the circuit obviously results in discharging them unequally, hence they require to be charged to a corresponding extent. This is accomplished by successively cutting the cells out of circuit as soon as they become fully charged, the last cell which was put into the circuit being fully charged in the shortest time, and so on. The amount of charge is determined by the methods already

given. If the cells employed are not injured by overcharging, they may be left in circuit until the entire battery is fully charged. This saves the trouble of operating the switch; but it is wasteful of energy, since the full counter E. M. F. and resistance of the charged cells must be overcome, which requires about 2.5 volts more per element. The clockwork could be set differently according to the season of the year or other conditions.

### REGULATION OF GENERATOR IN CHARGING STORAGE BATTERIES.

The variation in E. M. F. which occurs in accumulators renders it somewhat difficult to regulate the generators employed to charge them. A constant potential will give a decreasing rate of charge, owing to the gradual rise in counter E. M. F. This is advantageous, in that it enables the cells to receive a larger charge, but the increase in their voltage is so great that it is practically necessary to regulate the charging potential. In practice it is customary to maintain the charging current approximately constant for considerable periods of time, otherwise it would be difficult to determine the quantity of energy put into the battery, and its efficiency. When extra cells are used they facilitate the regulation of the generator, since they are gradually cut out as the E. M. F. rises.

If the lamps are supplied at the same time that the battery is being charged, some provision must be made for the fact that it may be necessary for the voltage of the dynamo to be considerably higher than that required by the lamps. One plan is to have two switches H and H connected to the reserve cells, as shown in Fig. 24, the charging current from the dynamo being led in through one, and the current for the lamps passing out through the other, so that the potential can be independently controlled in the two circuits. Another method is to insert counter E. M. F. cells (without active material) in the circuit between the dynamo and the lamps, in order to bring down the voltage of the former to suit the latter. The number of these cells is varied in accordance with the excess of the potential of the dynamo.

Simple resistance coils may be used in place of the counter E. M. F. cells to reduce the pressure; but the cells have the great advantage, that they have an effect practically independent of

variations in the current. All of these methods, however, involve a waste of power, the value of which in watts is the product of the current in amperes, and the number of volts by which the potential is cut down. In small plants this loss is not serious,

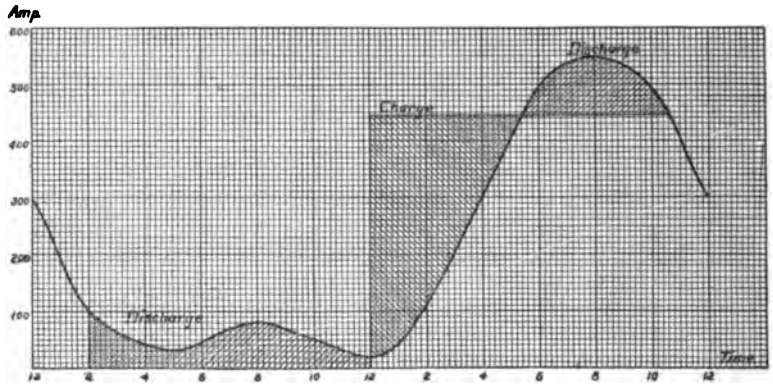



Fig. 26. Load Diagram of Case where Shunt Booster is Applicable.

but in large plants or central stations it may become very considerable.

**Booster Methods of Regulation.** The best plan is to make use of an "booster;" in which case the main dynamos are run at

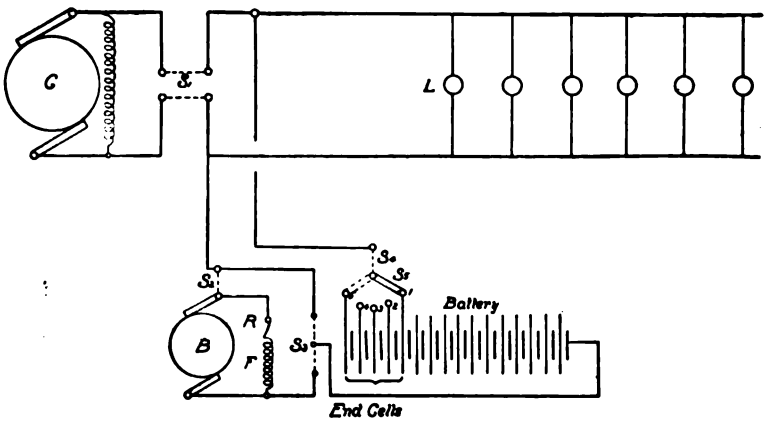



Fig. 27. Diagram of Shunt Booster Connections.

the proper voltage to supply the lamps directly, and the additional pressure required to charge the battery is furnished by the booster.

This is connected in series with the dynamo, being inserted in the circuit between the latter and the battery.

When a battery is placed at the end of a long feeder to compensate for line drop, and at light loads to act as a storage reservoir it is not usual to equip this "floating battery" with any regulating device. In such cases the battery is simply connected across the line, and the charge and discharge are determined by the feeder drop. For instance, when a small load is on the line, the drop is small, and the potential applied across the battery terminals is high enough to send a charging current into the battery, if the load on the line increases the drop naturally increases, the pressure at the end of the line falls, and if it falls below the battery voltage, the battery discharges in parallel with the generator, and carries a certain portion of the load. The "floating battery" has the advantage of simplicity, and acts immediately, as it has no time lag which is always present in any apparatus depending upon changes in magnetization. Usually the variations in voltage and the fluctuations in load are too great for successful operation of a floating battery on any but an electric railway or power circuit, and a booster would be required if incandescent lighting be a part of the load.

The duty of a booster is to vary the voltage at the battery terminals with variation in load, causing charging or discharging of current as conditions may require. The booster is an auxiliary dynamo, the E. M. F. of which is used to raise or lower the voltage in the battery circuit. These machines are classified as series, shunt, compound, differential and constant current boosters.

**The Shunt Booster** is a shunt dynamo, driven by any source of power, having its armature circuit in series with the line from generator to battery. This form is used in plants, where the battery is not designed to take up load fluctations, but is in service only to carry the peak of the load, being charged during periods of light load, and discharged in parallel with the generator. It acts to increase the voltage applied to the battery so that the charging current will flow into the latter. As a rule the battery used in conjunction with a shunt booster is made large enough to carry the entire load during the light load period. As the battery discharges and its voltage drops, the "end cells" (regulation cells)

are cut in and the proper voltage maintained. Fig. 26 shows a load diagram to which this system is applicable, and Fig. 27 shows the diagramation connections of this system. A rheostat is used to vary the booster voltage, so as to hasten the charging of the battery if desired. It is to be noted that the shunt booster is not applicable where there are sudden fluctuations that are great compared with the capacity of the generator, and that it is not automatic in changing from charge to discharge, the switching being performed by hand.

**Series Booster.** The connections are like those of the shunt booster with the battery and booster in series across the line but the field of the booster being in series with the battery circuit, its E. M. F. is zero when no current is flowing in or out of the battery. Should the voltage of the line rise, due to a decrease of load, and a charging current flow into the battery, the E. M. F. of the boosters would increase, and thus tend to increase the rate of charge. The reverse occurs when the battery discharges, as an increase of load on the line increases the current through the series field of the booster, thus raising the voltage of discharge so that the battery carries a larger part of the load.

This booster acts to compound the battery on discharge, and tends to maintain a constant voltage on the line. It depends on the fact that the generator voltage falls when the load increases; hence it is used with a shunt generator or equivalent source of supply.

This system is applicable to power but not to lighting purposes, and is similar in its operation to a "floating battery." It is not as extensively used as the compound and differential booster arrangements which give better regulation under similar conditions.

**Compound Booster.** This system is used on railway and power curcuits with great fluctuations in load, the battery acting to prevent excessive drop and to assist the generating machinery in carrying the load, relieving it from the strain of sudden rushes of current. The connections of this system are indicated in Fig. 28, and the operation is as follows: — Under normal load conditions the shunt field Fh of the booster creates an E. M. F. in the same direction as the battery, tending to discharge it. Calling Eg the

generator E. M. F., Ea the booster E. M. F. and Eb the battery E. M. F., we have Eg-Ea-Eb when no current is flowing into or out of the battery. In this case the generator carries the whole external load.

If the load increases Eg decreases, so that Eb-Ea is greater than Eg, and the battery begins to discharge. In discharging, the current passes through the series field Fs of the booster and produces a proportional E. M. F., acting with the shunt field to raise

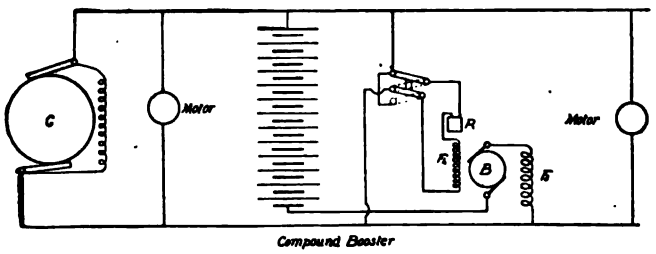



Fig. 28. Diagram of Compound Booster Connections.

Ea, thus increasing the battery discharge and shifting more of the load from the generator, until the system becomes balanced.

If the load on the external circuit be light, the generator voltage Eg rises and current flows into the battery. In this case

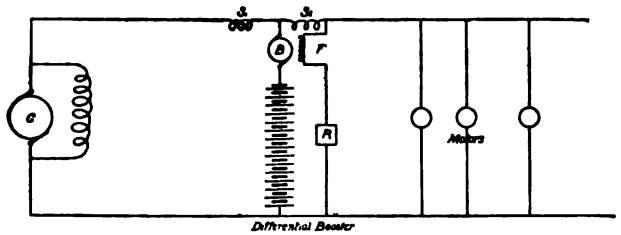



Fig. 29. Diagram of Differential Booster Connections.

the series field acts against the shunt field and decreases Ea, so that the generator voltage is greater than booster and battery voltage combined, thus increasing the rate of charge of the battery, until the load causes the generator voltage to drop to normal and the system is again balanced. The battery and booster can be placed at the power house or at the point at which the greatest drop is likely to occur.

A battery can also be used to help out the generators at the

peak of the load, by increasing the shunt field current and thus causing Ea-Eb to be greater than Eg.

Since this system also depends for its action upon the drop of voltage with increase of load, it is only applicable to shunt wound generators or equivalent source.

**Differential Boosters.** The differential booster system most commonly used, is shown in Fig. 29.

The compensating field $S_1$ prevents the variation of the battery E. M. F. from disturbing the equilibrium of the system. If the battery E. M. F. be lower than normal it will not discharge rapidly enough to relieve the generator from overload fluctuations,

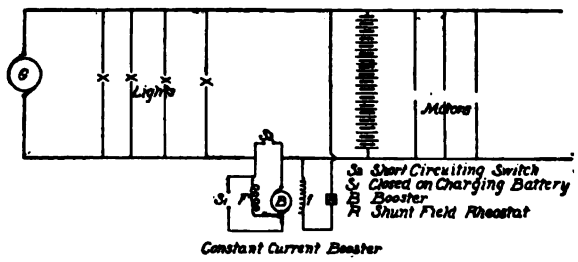



Fig. 30. Diagram of Constant Current Booster Connections.

unless the booster E. M. F. be increased, and the generator will therefore have to supply a current of greater than its normal value. If however a current of greater value than the normal flows through S, the value of (f–S) is decreased, and $S_2$ still further overpowers the resultant of ($f–S_1$) and causes a higher booster E M. F. tending to discharge the battery, and thus brings down the generator load to normal. Should the battery E. M. F. be above its normal value, the battery would discharge too rapidly and carry more than its share of the load; in this case (f–S) is greater than it should be, and the booster E. M. F. causes the load to become evenly distributed between the battery and generator.

In operating this system the varying load must be beyond the booster equipment. If desired the coils $S_1$ and $S_2$ may be short circuited so that the battery may be charged more rapidly.

**Constant Current Booster.** In systems having short lines and small drop it is often desirable to have the voltage fall on sudden application of an overload, so that the rush of excessive

current is prevented. This rush of current occurs in buildings where elevator and power motors constitute a large percentage of the load, and to prevent it, the constant current booster system is used.

Fig. 30 represents a constant current booster system, in which the main current passes through the armature and series field of the booster, and this current does not reverse.

The voltage impressed on a fluctuating load of motors on the right, is greater than that impressed on a non-fluctuating load of lamps on the left, by the amount of the booster voltage.

The shut coil f creates an E. M. F. in the same direction as the generator E. M. F., while the series coil F opposes it.

Should a load come in the motor portion of the circuit, the generator sends a greater current through the series coil S, the action of which reduces the booster E. M. F. in direct proportion to this rush of current, and causes the booster E. M. F. to vary inversely as the motor load, thus tending to maintain an almost constant current delivery from generator. If it is desired to have the battery furnish power to both the lights and motors, at periods of light load, and not use the generator, this can be done by simply opening generator switch and short circuiting the booster by closing switch $S_2$.

The switch $S_1$ is closed in charging the battery, as the rate of charge can be controlled by varying the shunt field resistance R. This is often done, when the battery has been carrying a heavy load for some time and the recharging must be hurried.

# APPENDIX

## QUESTIONS IN REVIEW

The following lists of questions afford the reader a means of testing his knowledge of the subjects treated in the present volume. Any one who has carefully read the foregoing subjects should be able to answer every question accurately. The reader is advised to go through the questions thoroughly, working out his answers and checking his results with the answers given. This will afford a valuable means of fixing the matter in mind. Students who are preparing for examinations for college, civil service or engineer's license will find the questions of the greatest value.

# REVIEW QUESTIONS

ON THE SUBJECT OF

# TYPES OF DYNAMO-ELECTRIC MACHINERY:

(DIRECT CURRENT).

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1. Show in what points modern generators are superior to older types.

2. State briefly what part the spider of a modern generator plays in the performance of the machine.

3. What is meant by a "generator of the engine type"?

4. What do you understand by an "iron-clad" armature?

5. Mention five different methods by which generators are driven.

6. What were the disadvantages of binding wires as applied to armatures, and by what means have they been dispensed with in modern generators?

7. Would you select an enclosed or open type of motor for operating a printing press which runs practically without intermission? State the reasons for your choice.

8. Discuss the advantages and disadvantages of direct-driven generators as compared with indirect-driven generators.

9. In modern machines of large size the outer yoke or frame is often stiffened by flanges. As the yoke is not subjected to outside mechanical strains, why is it necessary to stiffen it?

10. Describe different methods by which the armature may be removed from large size generators.

11. Describe the operation of the equalizer rings.

12. Describe briefly the improvements that have been made in the wearing qualities of modern commutators.

13. State what you consider to be good practice in deter-

mining current density for brushes of a low potential direct current generator.

14. State what you judge to be good practice in insulating armature coils.

15. Why should the efficiency of a 1000 K. W. generator remain high at low load while in the case of a 1 K. W. generator such results would not be expected?

16. What are the disadvantages of shafting as necessitated by indirect motor driving?

17. State why an "outboard" bearing is necessary in large belt-driven generators.

18. Show how a generator shaft is kept lubricated.

19. Why is a slow-speed motor preferred for general use in manufacturing plants?

20. In engine-type and direct-driven generators how is uniformity of rotation maintained?

21. Describe the dynamotor.

22. What do you consider to be good practice in calculating amperes per square inch of cross-section of conductor in armature coils for well-ventilated slow-speed engine-type generators? How many amperes would you permit an insulated armature conductor of bar shape, one-quarter inch thick and two inches wide, to carry?

23. In the Westinghouse arc lighting generator why should a separate exciter be recommended?

24. Indicate the present tendency in designing direct current motors, and state the advantages of connecting the motor directly to the machinery which it operates.

25. Give the essential features of a generating set for use on shipboard.

26. Discuss the various considerations that enter into the problem of equipping a manufacturing plant with motors.

27. By what means has it been made possible to use the electric motor in exposed positions and dust-loaded air?

28. What is good practice in allowing overload capacity in a railway motor?

29. Do you understand that slow-speed motors for a given output are heavier than high-speed motors, and if so, why?

# REVIEW QUESTIONS

ON THE SUBJECT OF

# ALTERNATING CURRENT MACHINERY.

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1. (*a*) Upon what factors does the frequency of an alternator depend? (*b*) What are the objections to very low and to very high frequencies?

2. (*a*) What is the meaning of the term *reactance?* (*b*) *Impedance?*

3. (*a*) Describe a disc armature. (*b*) What are its advantages?

4. Make a sketch of and describe briefly one form of inductor alternator.

5. State the essential requisites for a good transformer core.

6. Why cannot the speed of a synchronous motor vary except by varying the speed of the generator supplying the current?

7. How may a single-phase current be divided into two-phase currents?

8. What is meant by a *cycle?* An *alternation?*

9. Give the principle of a choking coil, and explain how the current strength is varied.

10. Why should the core losses in a transformer be made as low as possible?

11. (*a*) Explain the principle of an induction motor. (*b*) What is meant by the *slip* of an induction motor?

12. The voltage of a circuit supplied with an alternating current was measured by an alternating current voltmeter and found to be 500 volts. What could be assumed to be the maximum voltage?

13. When there is self-induction in a circuit, why does the current lag behind the E. M. F.?

14. (*a*) How is the voltage of a separately excited alternator usually regulated? (*b*) Of a self-excited shunt-wound alternator?

15. What are the two general methods of reducing the starting current in an induction motor?

16. Why does not an excessive current flow through the primary coil of a transformer, when the secondary circuit is open?

17. Give briefly the principle of a synchronizer.

18. Explain briefly why the product of the amperes and voltage of an alternating current circuit is not the true power if self-induction is present.

19. (*a*) What is the phase difference between the currents of a two-phase alternator? (*b*) When only three external wires are used, how much greater is the current in the common wire than that in each of the other wires? (*c*) Why is it not twice the value?

20. Describe the commutator required when an alternator is provided with a self-exciting series winding.

21. When two alternators are to be connected in parallel, why is it important that they should first be brought into synchronism?

22. How may the power of a two-phase system be measured, three conducting wires being used?

23. State the advantages and disadvantages of inductor alternators.

24. When the current supplied by the secondary of a transformer is increased, why does the primary current also increase?

25. The power factor of a motor at full load is .78. If the apparent power is 4.8 K.W., what is the true power?

26. Describe the star and mesh form of connecting three-phase windings.

27. Explain the principle of a compensating voltmeter.

28. Explain why the E. M. F. due to self-induction follows the current passing by a phase difference of 90°.

29. Describe a method of making a synchronous motor self-starting.

30. Why is the alternating current system preferred to the direct current system in transmitting power long distances?

# REVIEW QUESTIONS

ON THE SUBJECT OF

# ELECTRIC LIGHTING.

---

1. What objection is there to connecting many arc lamps on the mains of a low potential parallel system?

2. The efficiency of an arc lamp is about how much greater than that of an incandescent?

3. State the important advantages of the two-wire parallel system.

4. Define a circular mil.

5. A wire having a cross-section of 10,000 circular mils has what diameter?

6. How is the mean spherical candle power of a lamp obtained?

7. What determines the resistance of an incandescent lamp?

8. What unit of light is in common use in this country?

9. There are installed on a 110-volt two-wire system 850 lamps of 16 c. p., each taking .6 ampere, and 420 lamps of 32 c. p., each of which takes 1.1 amperes. If 6% of the energy supplied by the generator is lost in the wiring, what amount of energy in kilowatts must be supplied to the system when all the lamps are on? Ans. 113.7+ K. W.

10. The increase of resistance of copper is what per cent per degree Fahrenheit?

11. Why is it necessary to exhaust the air from the bulb of an incandescent lamp?

12. In measuring the candle power of an incandescent lamp, the disk of the Bunsen photometer showed equal illumination on both sides when 6.4 ft. from the lamp whose candle power was to be found and 3.6 ft. from the standard lamp whose candle power was known to be 12. What was the candle power of the incandescent lamp? Ans. 37.9+ c. p.

13. Why are copper conductors more suitable than those of other metals for electric lighting purposes?

14. What must the regulator of the arc lamp accomplish?

15. What objection is there to running many motors on a series circuit?

16. The mean spherical candle power of an incandescent lamp was found to be 15. During the measurement of the candle power, the average voltage at the lamp terminals was 106 and the current .53 ampere. (*a*) What was the number of watts consumed? (*b*) The watts per candle power? (*c*) The resistance of the lamp?

Ans. (*a*) 56.18 watts.
(*b*) 3.74+ watts per c. p.
(*c*) 200. ohms.

17. Why are stranded conductors used?

18. What are cored carbons, and what advantages are gained by their use?

19. Eight per cent. of the energy supplied by a generator is lost in the conductors. The voltage at the lamps is 101; what is the voltage at the generator? Ans. 109.7+ volts.

20. What is a differential electromagnet? Explain how it acts to raise and lower its soft iron core when used in the arc lamp regulator.

21. How is the efficiency of an incandescent lamp determined?

22. What are the advantages of the three-wire system?

23. An arc lamp rated at 2,000 c. p. requires how many watts for its proper operation? What is its actual mean spherical candle power?

24. What causes the high temperature of the arc?

25. A good insulator must have what properties?

26. (*a*) Which carbon is consumed the more rapidly in the direct current arc lamp? (*b*) In the alternating current arc lamp?

27. Give briefly the process of preparing a filament for an incandescent lamp.

28. What are the advantages of the underground system?

29. What is the drop in 79 ft. of No. 14 B. & S. wire of 97% conductivity, when the current is 7 amperes?

Ans. 1.46+ volts.

30. If the allowable drop in 110 volt mains supplying 206 lamps of 16 c. p. at a distance of 104 ft. is 1.8 volts, what must be the size of the mains? Ans. No. 00 B. & S.

31. Why should the positive carbon be above the negative in the direct current arc lamp?

32. In calculating the size of wire for a circuit it was found that with the allowable loss of energy the size could be No. 2 B. & S. The current was 82 amperes. Why should not this size be used?

33. What determines the color of the arc light?

34. Upon a two-wire 107 volt parallel system it was desired to connect two arc lamps in series between the mains. Each lamp requires 45 volts and 9 amperes for its operation; what must be the value of the steadying resistance inserted?

Ans. 1.88+ ohms.

35. If the drop in 300 ft. of No. 2 wire is 2.3 volts, what is the current? Ans. 46.8+ amperes.

36. Ten 16 c. p. lamps are to be connected on a 110 volt circuit which is to have a length of 90 ft. Allowing a drop of .8 volt what size of wire must be used? Ans. No. 12 B. & S.

37. The use of interior conduits in wiring a building has what advantages?

38. What is a focusing arc lamp?

39. What size of wire is required to supply eighty-four 16 c. p. and fourteen 32 c. p. lamps at a distance of 184 ft. allowing a drop of 2.5 volts, it being a 110 volt circuit?

Ans. No. 0 B. & S.

40. In what respect does the series incandescent lamp differ from the constant potential incandescent lamp?

41. What is the principal objection to the direct coupling of engines and dynamos?

42. On a 55 volt circuit there are ninety 16 c. p. lamps at a distance of 230 ft. from the generator. The drop allowed is 3.5 volts; what size of wire is necessary for the mains?

Ans. No. 00 B. & S.

43. Three-wire mains are to extend a distance of 400 ft. to supply five hundred 110 volt lamps of 16 c. p. The drop allowed is 7 volts; what must be the size of the mains?

Ans. No. 000 B. & S.

# REVIEW QUESTIONS

ON THE SUBJECT OF

# ELECTRIC RAILWAYS.

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1. (*a*) Upon what does the heat developed in an electrical heater depend? (*b*) Explain the method of obtaining different degrees of heat in the electric car. (*c*) How much power in K. W. is consumed in heating a car, if the heaters take 6 amperes and the cars are run on a 500-volt circuit?

2. (*a*) State briefly the essential requisites for a first-class car motor. (*b*) Describe one form of motor suspension.

3. What is the speed of the motor armature of a car going at the rate of 8 miles per hour? Diameter of car wheel = 33″, single reduction gear, 14 teeth on the pinion, 72 on the axle gear.

4. (*a*) Explain the series-parallel method of controlling the speed of a car, and the method of gradually increasing the speed of a car by the General Electric "K" type controller. (*b*) Indicate the course of the current when the controller handle is on the sixth notch in Fig. 18.

5. What is the weight of a car if it requires 5 men to keep it in motion on a level and straight track, each man exerting a force of 150 pounds?

6. Give the principle of a good form of electric brake.

7. Draw a diagram showing the course of the current in the return circuit when the rail is paralleled by a large water main. Denote the points at which the strongest electrolytic action will take place, assuming the trolley positive.

8. What are the advantages of the third-rail system?

9. What are the most important factors to be considered in locating a power house for a given system?

10. Explain why the speed of a car increases by causing the different combinations of storage batteries shown in Fig. 47.

11. How may the alternating current be applied to electric railway work, direct current motors being used on the cars?

12. When should high and when low speed engines be used in a power house?

13. (*a*) How is the electrical circuit maintained at switches and crossings in the third rail system? (*b*) How is the car enabled to cross such places?

14. Give the principle of the automatic circuit breaker.

15. What are anchor wires and why are they used?

16. At what part of the wiring of a car is the choke coil inserted?

17. What is the advantage of the water-tube boiler as regards its use in electric railway work?

18. Calculate the voltages at the motor terminals corresponding to the first four combinations of storage batteries shown in Fig. 47. Assume that the drop through the inserted resistance in the third combination is 25 volts.

19. By what method is the danger of an over-discharge in storage battery work greatly reduced?

20. Explain the function of the choke coil as used in car wiring.

21. Explain the difference between the generator panel and feeder panel of a railway switchboard.

22. How is the current conducted from the trolley wire to the car?

23. Why is it necessary to bond the rails?

24. State the advantages to be gained by using accumulators in power plants.

25. Why is it necessary to use feeders on long lines?

26. Give a method of stopping a car by the motors in case the brakes should fail.

27. Explain why pipes in the vicinity of the power house should be connected electrically to the negative terminal of the generator when the trolley is positive.

28. What is meant by a *transition curve* in track construction?

29. Describe the Chicago rail bond.

30. (*a*) Determine by means of Figs. 44 and 45 the approximate power required to propel a 30 ton car at a speed of 8 miles an hour up a 3% grade. (*b*) A 100 ton car at a speed of 37 miles an hour on a level track. (*c*) If the efficiency of the motors is 80%, what power must be delivered to both cars

# REVIEW QUESTIONS

ON THE SUBJECT OF

# CENTRAL STATIONS AND POWER TRANSMISSION.

1. Give briefly the advantages obtained by using, under favorable circumstances, a few large transformers with secondary mains, in place of single transformers for each consumer.

2. What may be the causes of overheating in the field coils?

3. Why is copper preferable to brass for the conducting parts of switches?

4. Why is it desirable to have a station centrally located with regard to its load?

5. Give the principal objection to induction motors.

6. For what reasons cannot full reliance be placed upon the melting of a fuse when the current reaches a certain value?

7. Before starting up a dynamo for the first time what precautions should be taken?

8. How may a moderate amount of sulphating be removed from the plates of an accumulator?

9. Referring to the switchboard shown in Fig. 8, what steps would be taken to connect circuit *5* in series with circuit *11* and dynamo *L*?

10. The field coils of a dynamo are connected so that the current generated by the machine destroys the residual magnetism. How could the fault be remedied?

11. Describe a method for cooling the water used for condensing purposes so that it may be used continuously.

12. On the three-phase system using three wires, how are the transformers connected for reducing the voltage, the star arrangement being used?

13. By what is the capacity of constant-current arc-light machines limited?

14. Why is it preferable to remove the load from a motor before stopping it?

15. Give four different ways of ascertaining if an accumulator is fully charged.

16. What apparatus usually appears on a switchboard for arc lighting?

17. What is the great difficulty to be overcome in providing an entirely serviceable and satisfactory lightning arrester?

18. How may the use of a vertical belt be avoided if the dynamo is located above the driving wheel of the engine?

19. Bearing in mind the fact that a heavy load on a shunt generator means low external resistance, how is the failure of such a machine to build up under heavy load explained?

20. What are the advantages and disadvantages of slate as a material for switchboards?

21. Why should the armature shaft have a small end play in its bearings?

22. State the objections to installing only a single generating unit to carry the entire load of a central station.

23. What are the different pieces of apparatus which usually appear upon a switchboard for direct-current constant potential machines?

24. What are the advantages of a belted connection between engines and dynamos over direct connection?

25. How may the source of excessive heating in a dynamo be located, when the dynamo appears to be uniformly heated?

26. What must be considered in deciding upon the location for the switchboard in a central station?

27. How should a dynamo running in parallel with other machines be disconnected from the circuit?

28. What is the objection to placing storage batteries in the same room with the generating apparatus?

29. In selecting a dynamo what general features should be considered?

30. State the reason why better regulation is secured with large machines, by running the equalizer directly between them instead of to the switchboard.

# REVIEW QUESTIONS

ON THE SUBJECT OF

# STORAGE BATTERIES.

1. What is the lowest value to which a lead battery should be discharged?

2. What means may be employed to make up for the drop in potential of storage batteries during discharge?

3. What causes sulphating?

4. What plate of a storage battery is the positive?

5. Describe the several indications by which the amount of charge in a storage battery can be determined.

6. How is the capacity of a storage battery usually expressed?

7. What is an electrolyte?

8. What is meant by floating battery, and when is it applicable?

9. How must a storage battery room be arranged?

10. What causes buckling?

11. Why are there always more negative plates than positive plates in a storage battery?

12. Give several applications of storage batteries.

13. When a storage battery is charged what is found on the positive plate and what is found on the negative plate, and what occurs when the cell is discharged?

14. What is the maximum voltage obtainable from a lead storage cell?

15. How may sulphating and buckling be prevented?

16. How would you put a battery out of commission for a long period, and how would you place it in service again?

17. What is the difference in construction between Faure and Planté plates?

18. What is the essential difference between a primary and storage battery?

19. What instruments are required in a storage battery switchboard?

20. If a battery be discharged at a greater rate than its normal what happens to the capacity of the cell for that moment?

21. What impurities in the electrolyte must be guarded against, how is their presence caused, and how determined?

22. Which type of cell has the larger storage capacity per lb. of cell, and why; the Fauré or Plante?

23. Why is the storage battery useful in electrical laboratories?

24. What is the specific gravity of the electrolyte of a lead cell when fully charged, and about what when discharged?

25. What is the constant current booster system, and where is it most applicable?

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